JOHNS HOPKINS
WHITING SCHOOL
*of* ENGINEERING

# Engineering for Professionals

*Part-Time and Online Graduate Education in Engineering and Applied Sciences*

2015–2016
Part-Time Graduate Programs
ep.jhu.edu

Dear Students,

The most successful engineers are those who never stand still when it comes to their education and their careers. Rather, it is those engineers who are committed to remaining at the forefront of their professions, who strive continuously to be well versed in the latest technologies, and who have the ability to continuously learn how their fields are evolving and which skills and knowledge are necessary to stay ahead of the curve who will achieve success.

At the Whiting School of Engineering, our Engineering for Professionals programs provide these motivated working engineers—in our region and around the world—with the tools and experiences necessary to enhance their education in ways that will have a direct positive impact on their professional lives.

We provide our engineering students with academic offerings of the highest quality, with all the value and prestige of a Johns Hopkins education. The breadth of our degree and certificate programs, the real-world experience of our faculty, and our state-of-the-art instructional methods enable us to provide students with unparalleled opportunities. At Engineering for Professionals, you will learn from experienced working professionals and outstanding academic faculty. These instructors speak directly to the applications of the course work you will study and continually improve and update content to encompass the very latest in both the theoretical understanding and applications in their areas of expertise.

In addition to the tremendous academic opportunities you will be afforded by enrolling in a Johns Hopkins Engineering for Professionals program, as a student here, you also will become part of a remarkable community. As a student and, later, as an alumnus, you will be a member of the uniquely successful Johns Hopkins family, connected forever to the traditions and achievements of one of the world's most esteemed academic research institutions.

Congratulations on choosing Johns Hopkins.

Sincerely,

Ed Schlesinger
Benjamin T. Rome Dean
Whiting School of Engineering

JOHNS HOPKINS
WHITING SCHOOL
*of* ENGINEERING

# Engineering for Professionals
# Part-Time and Online Graduate Education
# Academic Year 2015–2016

# 2015–2016 ACADEMIC CALENDAR

**Application Deadline**: The admissions process is handled on a continuing basis.

**Important Semester Dates**

| | Summer 2015 | Fall 2015 | Spring 2016 |
|---|---|---|---|
| First Day of Classes | May 26 | August 31 | January 25, 2016 |
| Holidays | July 4 | November 23–29 | March 14–20 |
| Graduation Application Deadlines | August 1 | December 1 | May 1 |
| Last Day of Classes | August 17 | December 15 | May 8 |

No classes on Tuesday, October 20, for the Fall Faculty Meeting.

**Registration Deadlines**

| | Summer 2015 | Fall 2015 | Spring 2016 |
|---|---|---|---|
| Registration Opens | March 26 | July 2 | October 22 |
| Final Day to Add | 2nd Class Meeting | September 14 | February 7, 2016 |
| Final Day to Add Online Courses | June 4 | September 12 | January 31, 2016 |
| Withdrawal/Audit Deadline | 9th Class Meeting | November 10 | April 1 |

**Tuition Payment Deadlines***

| | Summer 2015 | Fall 2015 | Spring 2016 |
|---|---|---|---|
| | June 9 | September 15 | February 8, 2016 |

**There will be a $150 late fee if tuition is not paid by the due date.*

Whiting School Graduate Ceremony is Wednesday, May 18, 2016.

University Commencement Day is Thursday, May 19, 2016.

# CONTACT INFORMATION

Johns Hopkins Engineering for Professionals
Dorsey Student Services Center
6810 Deerpath Road, Suite 100
Elkridge, MD 21075
410-516-2300
ep.jhu.edu
jhep@jhu.edu

## GENERAL INFORMATION AND REQUESTS

Admissions/Registration (Dorsey Student Services Center) ................ 410-516-2300

## LOCATIONS

Applied Physics Laboratory (from Baltimore) ................ 443-778-6510
................ (from Washington) ................ 240-228-6510
Crystal City Center ................ 240-228-2912
Dorsey Student Services Center................ 410-516-2300
Homewood Campus ................ 410-516-8000
Southern Maryland Higher Education Center ................ 301-737-2500
University Center of Northeastern Maryland................ 443-360-9200

## STUDENT SERVICES

Disability Services................ 410-516-2306
Financial Aid (146 Garland Hall) ................ 410-516-8028
International Office................ 410-516-1013
Johns Hopkins Student Assistance Program ................ 443-287-7000
Student Accounts (Johns Hopkins Engineering for Professionals) ................ 410-516-2276
Student Accounts (Homewood) ................ 410-516-8158
Transcripts (75 Garland Hall)... 410-516-7088
University Registrar (75 Garland Hall)................ 410-516-8083
Veterans Certification (75 Garland Hall) ................ 410-516-7071

## ONLINE INFORMATION

Application ................ ep.jhu.edu/apply
Catalog................ep.jhu.edu/catalogs
Course Schedule ................ep.jhu.edu/schedule
Graduation Information................ep.jhu.edu/graduation
Johns Hopkins Engineering for Professionals Forms................ep.jhu.edu/student-forms

## TEXTBOOKS

All Locations................ ep.jhu.edu/textbooks
Information in this catalog is current as of publication in March 2015. For all updates, please visit ep.jhu.edu.

The university of necessity reserves the freedom to change without notice any programs, requirements, or regulations published in this catalog. This catalog is not to be regarded as a contract. Multiple means of communication may be used by the university for announcing changes of this nature, including, but not exclusive to, e-mail and/or paper notice. Students are responsible for providing current e-mail and mailing address information to the university administrative offices.

# ENGINEERING ADMINISTRATION

## WHITING SCHOOL OF ENGINEERING

T. E. SCHLESINGER
Benjamin T. Rome Dean

## JOHNS HOPKINS ENGINEERING FOR PROFESSIONALS

DEXTER G. SMITH
Associate Dean

DAN HORN
Assistant Dean of Academic Programs

TIM JARRETT
Director, Software Engineering

MARY KELTY
Director, Center for Learning Design and Technology

MARIELLE NUZBACK
Senior Director of Operations

KEN SCHAPPELLE
Manager of Recruitment, Marketing, and Communications

DOUG SCHILLER
Director, Admissions and Student Services

## APPLIED PHYSICS LABORATORY EDUCATION CENTER

HARRY K. CHARLES JR.
Education Center Program Manager

CHRISTINE M. MORRIS
Partnership Manager

TRACY K. GAUTHIER
Education Center Operations Coordinator

## GRADUATE PROGRAM ADMINISTRATION

HEDY V. ALAVI
Program Chair, Climate Change, Energy,
and Environmental Sustainability
Program Chair, Environmental Engineering
Program Chair, Environmental Engineering and Science
Program Chair, Environmental Planning and Management

MICHAEL BETENBAUGH
Program Chair, Chemical and Biomolecular Engineering

ROBERT C. CAMMARATA
Program Chair, Materials Science and Engineering

HARRY K. CHARLES JR.
Program Chair, Applied Physics

EILEEN HAASE
Program Chair, Applied Biomedical Engineering

BRIAN K. JENNISON
Program Chair, Electrical and Computer Engineering

THOMAS A. LONGSTAFF
Program Chair, Computer Science
Program Chair, Cybersecurity
Program Chair, Information Systems Engineering

RONALD R. LUMAN
Program Chair, Systems Engineering

ANDREA PROSPERETTI
Program Chair, Mechanical Engineering

RACHEL SANGREE
Program Chair, Civil Engineering

JAMES C. SPALL
Program Chair, Applied and Computational Mathematics

JOSEPH J. SUTER
Program Chair, Engineering Management
Acting Program Chair, Space Systems Engineering
Program Chair, Technical Management

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# THE JOHNS HOPKINS DISTINCTION

The Johns Hopkins University opened in 1876, with the inauguration of its first president, Daniel Coit Gilman. "What are we aiming at?" Gilman asked in his installation address. "The encouragement of research…and the advancement of individual scholars, who by their excellence will advance the sciences they pursue, and the society where they dwell."

The mission laid out by Gilman remains the university's mission today, summed up in a simple but powerful restatement of Gilman's own words: "Knowledge for the world."

What Gilman created was a research university, dedicated to advancing both students' knowledge and the state of human knowledge through research and scholarship. Gilman believed that teaching and research are interdependent, that success in one depends on success in the other. A modern university, he believed, must do both well. The realization of Gilman's philosophy at Johns Hopkins, and at other institutions that later attracted Hopkins-trained scholars, revolutionized higher education in America, leading to the research university system as it exists today.

After more than 130 years, Johns Hopkins remains a world leader in both teaching and research. Eminent professors mentor top students in the arts and music, the humanities, the social and natural sciences, international studies, education, business, and the health professions. Those same faculty members, and their research colleagues at the university's Applied Physics Laboratory, have each year since 1979 won Johns Hopkins more federal research and development funding than any other university.

Johns Hopkins University is accredited by the Middle States Commission on Higher Education and is privately endowed. Nine divisions of the university grant degrees. They are the Whiting School of Engineering, the Zanvyl Krieger School of Arts and Sciences, the School of Education, the School of Medicine, the School of Nursing, the Bloomberg School of Public Health, the Peabody Institute, the Carey Business School, and the Paul H. Nitze School of Advanced International Studies. The tenth division of the university is the Applied Physics Laboratory (APL), a research institute.

# WHITING SCHOOL OF ENGINEERING

The school consists of the following full-time departments: Applied Mathematics and Statistics, Chemical and Biomolecular Engineering, Civil Engineering, Computer Science, Electrical and Computer Engineering, Geography and Environmental Engineering, Materials Science and Engineering, Mechanical Engineering, and, in collaboration with the School of Medicine, Biomedical Engineering. Information about full-time education may be found in the Johns Hopkins University Arts and Sciences/Engineering Undergraduate and Graduate Catalog or on the web at engineering.jhu.edu. Admission information for full-time undergraduate education is available from the Office of Admissions, Mason Hall, 3400 N. Charles Street, Homewood Campus, 410-516-8171. For full-time graduate education, students should contact the department in which they are interested.

The university has offered part-time engineering education since before World War I. Over the intervening decades, thousands of working engineers and scientists have earned graduate and undergraduate degrees through part-time study, achieving personal and professional goals without interrupting their careers. Today, through the Johns Hopkins Engineering for\ Professionals program, the Whiting School continues the university's tradition of offering advanced engineering education to working professionals.

Johns Hopkins Engineering for Professionals courses are continually updated for relevance, addressing industry trends and the latest advances in engineering and applied science fields. Classes are scheduled at convenient times during late afternoons and evenings and on Saturdays and at a number of locations throughout the Baltimore-Washington region. Also, each year, Johns Hopkins Engineering for Professionals offers an increasing number of courses and degree programs online to allow professionals who cannot attend classes at our education centers the ability to advance their education.

# GRADUATE PROGRAMS

Graduate students in the Johns Hopkins Engineering for Professionals program constitute one of the nation's largest student bodies in continuing engineering education at the master's-degree level. Graduate courses are offered at seven locations and online. Students receive individual attention from their advisors and instructors and benefit from small classes and well-equipped laboratory, computing, and classroom facilities.

Almost all courses are scheduled in the late afternoon or evening Monday through Friday, on Saturdays, online, or Virtual Live so that students can further their education without interrupting their careers. Graduate students may take courses at any Hopkins location listed in the Degree and Certificates Offered chart on page 19. Please note that all courses are not offered at all locations.

The university is accredited by the Middle States Commission on Higher Education, 3624 Market St., Philadelphia, PA 19104-2680; 215-662-5606. The Accreditation Board for Engineering and Technology (ABET) is the accrediting authority for engineering and technology programs in the United States. Universities and colleges may choose to have their basic (undergraduate) or advanced (graduate) programs accredited. Nearly every engineering school, including the Whiting School, chooses to have its basic programs accredited by ABET.

# DEGREES AND CERTIFICATES

The Johns Hopkins University offers a variety of degrees and certificates to students in the Whiting School of Engineering. Requirements for each discipline are detailed in the individual program listings in this catalog.

## MASTER OF SCIENCE

Programs are offered in Applied Biomedical Engineering, Applied and Computational Mathematics, Applied Physics, Computer Science, Cybersecurity, Electrical and Computer Engineering, Engineering Management, Environmental Engineering and Science, Environmental Planning and Management, Information Systems Engineering, Space Systems Engineering, Systems Engineering, and Technical Management.

## MASTER'S

Programs are offered in Chemical and Biomolecular Engineering, Civil Engineering, Environmental Engineering, Materials Science and Engineering, and Mechanical Engineering.

## MASTER OF SCIENCE IN ENGINEERING

One program is offered in Systems Engineering.

## JOINT DEGREE AND DUAL PROGRAM

A joint degree in Bioinformatics is offered by Johns Hopkins Engineering for Professionals and the Zanvyl Krieger School of Arts and Sciences Advanced Academic Programs. The description of this degree can be found in the Computer Science section on page 38. The administration is handled by the Zanvyl Krieger School of Arts and Sciences, and applications for admission to the Master of Science in Bioinformatics must be submitted directly to the Zanvyl Krieger School of Arts and Sciences at bioinformatics.jhu.edu.

A dual program is available, jointly offered by Johns Hopkins Engineering for Professionals' Environmental Planning and Management program and the Applied Economics program at the Zanvyl Krieger School of Arts and Sciences Advanced Academic Programs. A detailed description of this program can be found in the Environmental Planning and Management section on page 61. Students applying to the dual-degree program will download the application and submit supporting documents and the application fee to Advanced Academic Programs at advanced.jhu.edu. The application will be forwarded to Johns Hopkins Engineering for Professionals. Each program decides on admissions separately.

Johns Hopkins Engineering for Professionals' Environmental Engineering, Science, and Management offers three dual-degree programs with the Carey Business School. Students may pursue the Master of Environmental Engineering, the Master of Science in Environmental Planning and Management, or the Master of Science in Environmental Engineering and Science, each combining with the Master of Business Administration for three distinct dual-degree programs. A detailed description of these programs can be found in the Environmental Engineering and Science section on page 59. Students applying to any of the three dual-degree programs will download the application and submit supporting documents and to Johns Hopkins Engineering for Professionals at ep.jhu.edu. The completed application will be forwarded to the admissions office at the Carey Business School. Each program decides on admissions separately.

## POST-MASTER'S CERTIFICATE

This certificate is awarded upon completion of six courses beyond the master's degree in the same or a closely related discipline area.

### GRADUATE CERTIFICATE

This certificate is awarded upon completion of a select number of courses of graduate study within one of the master's degree discipline areas.

### NON-DEGREE-SEEKING STUDENTS

Students who wish to enroll in courses but are not interested in pursuing a degree or certificate may enroll as Special Students.

## ONLINE LEARNING

Johns Hopkins Engineering for Professionals has offered classes online since 2001, consistently delivering a unique educational experience that is both academically rigorous and highly practical. Johns Hopkins Engineering for Professionals' online programs complement the busy schedules of today's practicing engineers and scientists by allowing students to pursue studies face to face, online, or via a combination of both formats. Courses are consistently being developed for online delivery. Current course offerings are in the following programs:

- Applied Biomedical Engineering
- Applied and Computational Mathematics
- Climate Change, Energy, and Environmental Sustainability*
- Computer Science*
- Cybersecurity*
- Electrical and Computer Engineering*
- Engineering Management
- Environmental Engineering*
- Environmental Engineering and Science*
- Environmental Planning and Management*
- Information Systems Engineering*
- Mechanical Engineering
- Space Systems Engineering
- Systems Engineering*
- Technical Management*

*Programs marked with an asterisk (*) can be completed fully online.*

Online courses are delivered in a paced, asynchronous mode over the Internet. Recorded lectures with associated multimedia content are augmented with online discussions and weekly synchronous office hours. Prospective and current students should consult ep.jhu.edu/online-learning for the current online course offerings, course schedules, and procedures for online programs.

### ONLINE COURSE REGISTRATION

Online course registration adheres to the same schedule followed by on-site courses. Enrollment is granted on a first-come, first-served basis, and new and returning online students are strongly encouraged to register early. The deadline for adding online courses is a week after the first day of classes each term, which is earlier than the deadline for adding conventional courses. See the 2015–2016 Academic Calendar on page i for exact dates for each term.

### VIRTUAL LIVE FORMAT

This newly developed format is a combined in-person and online course delivery method. In-person class sessions are held synchronously with a virtual live session. The virtual live session is for students who are unable to attend in person but prefer a synchronous "live" class. The virtual student participates via a web-conferencing tool enabling two-way communication and live video feed with the in-person class.

### ONLINE STUDENT SUPPORT SERVICES

Johns Hopkins Engineering for Professionals makes every effort to provide online students access to a full range of services and resources comparable to those available to students taking on-site courses. Online students can register, pay their tuition, receive academic advising, purchase course textbooks, access Johns Hopkins University library holdings, view transcripts, and access grades and various other academic services all online. Once admitted, students gain access to the Johns Hopkins portal site, myJH, which provides quick access to many of these services.

### ONLINE EDUCATION STATE AUTHORIZATION APPLICATION POLICY

Prospective students from select states are prohibited from applying to online degree programs at Johns Hopkins Engineering for Professionals. For a breakdown by degree or certificate program, please see the chart on page 4. For the most recent State Authorization application information, please visit ep.jhu.edu.

### ONLINE EDUCATION STATE AUTHORIZATION REFUND POLICY

Students from Arkansas, Iowa, Minnesota, and Wisconsin should be aware of state-specific information for online programs.

# ONLINE EDUCATION STATE AUTHORIZATION CHART

| Program Name | Credential | AL | AR | IA | MN | OR | WI | IN | ND | DE | KS | KY | LA | MA | MO | NC | NH | NM | NV | OH | WA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Applied Biomedical Engineering | MS | no | no | yes | no | **yes** | no | yes | xmpt | | | | | | | | | | | | |
| | PMC | no | no | yes | no | **yes** | no | yes | xmpt | | | | | | | | | | | | |
| Climate Change, Energy, and Environmental Sustainability | PMC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| Computer Science | MS | yes | yes | yes | yes | **yes** | yes | yes | xmpt | | | | | | | | | | | | |
| | PMC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| Cybersecurity | MS | yes | no | yes | yes | **yes** | yes | yes | xmpt | | | | | | | | | | | | |
| | PMC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| Electrical and Computer Engineering | MS | yes | yes | yes | yes | **yes** | yes | yes | xmpt | | | | | | | | | | | | |
| | PMC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| | GC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| Engineering Management | MEM | 1/2 | no | yes | yes | **yes** | yes | yes | xmpt | | | | | | | | | | | | |
| Environmental Engineering | MEE | yes | no | yes | yes | **yes** | yes | yes | xmpt | | | | | | | | | | | | |
| | PMC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| | GC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| Environmental Engineering and Science | MS | yes | no | yes | yes | **yes** | yes | yes | xmpt | | | | | | | | | | | | |
| | PMC | yes | yes | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| | GC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| Environmental Planning and Management | MS | yes | no | yes | yes | **yes** | yes | yes | xmpt | | | | | | | | | | | | |
| | PMC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| | GC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| Information Systems Engineering | MS | yes | no | yes | yes | **yes** | yes | yes | xmpt | | | | | | | | | | | | |
| | PMC | yes | yes | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| | GC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| Space Systems Engineering | MS | 1/2 | no | yes | yes | **yes** | yes | yes | xmpt | | | | | | | | | | | | |
| Systems Engineering | MS | yes | no | yes | yes | **yes** | yes | yes | xmpt | | | | | | | | | | | | |
| | MSE | yes | yes | yes | yes | **yes** | yes | yes | xmpt | | | | | | | | | | | | |
| | PMC | yes | yes | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| | GC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| Technical Management | MS | yes | no | yes | yes | **yes** | yes | yes | xmpt | | | | | | | | | | | | |
| | PMC | yes | yes | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |
| | GC | yes | no | yes | yes | **yes** | n/a | yes | xmpt | | | | | | | | | | | | |

### ARKANSAS

Students should be aware that these degree programs may not transfer. The transfer of course/degree credit is determined by the receiving institution.

### IOWA

Johns Hopkins University is registered by the Iowa College Student Aid Commission (ICSAC) on behalf of the State of Iowa. Iowan residents who wish to inquire about Johns Hopkins University or file a complaint may contact the ICSAC at 430 E. Grand Avenue, Third Floor, Des Moines, IA 50309 or 515-725-3400.

### MINNESOTA

Johns Hopkins University is registered as a Private Institution with the Minnesota Office of Higher Education pursuant to sections 136A.61 to 136A.71. Registration is not an endorsement of the institution. Credits earned at the institution may not transfer to all other institutions.

### WISCONSIN

A student will receive a full refund of all money paid if the student:

Cancels within the three-business-day cancellation period under EAB 6.04;

1. Was accepted but was unqualified and the school did not secure a disclaimer under EAB 9.04; or
2. Enrollment was procured as the result of any misrepresentation in the written materials used by the school or in oral representations made by or on behalf of the school.

Refunds will be made within 10 business days of cancellation.

A student who withdraws or is dismissed after attending at least one class, but before completing 60% of the instruction in the current enrollment period, is entitled to a pro rata refund as follows:

| At least | But Less Than | Refund of Tuition |
|---|---|---|
| unit/class | 10% | 90% |
| 10% | 20% | 80% |
| 20% | 30% | 70% |
| 30% | 40% | 60% |
| 40% | 50% | 50% |
| 50% | 60% | 40% |
| 60% | no | no refund |

As part of this policy, the school may retain a one-time application fee of no more than $100. The school will make every effort to refund prepaid amounts for books, supplies, and other charges. A student will receive the refund within forty days of termination date. If a student withdraws after completing sixty percent of the instruction, and withdrawal is due to mitigating circumstances beyond the student's control, the school may refund a pro rata amount.

A written notice of withdrawal is not required.

## ADMISSION REQUIREMENTS

Johns Hopkins Engineering for Professionals encourages all students who have serious academic interests to apply. Qualified students may structure their course work to pursue a specific degree or certificate program, or they may take courses under the Special Student (i.e., non-degree-seeking) designation if they have met program and course prerequisites. An applicant may be admitted in one of four categories:

1. Master's Degree candidate
2. Post-Master's Certificate candidate
3. Graduate Certificate candidate
4. Special Student

An applicant must meet the general admission requirements appropriate for all graduate study and the specific admission requirements for the desired program. Note that these requirements represent minimum standards for admission; the final decision on an applicant's suitability for a given program is made by the admissions committee for that program. The general application procedures and admission requirements are stated below. Please refer to the individual program sections for additional specific requirements.

Applicants who have been dismissed or suspended by any college or university, including Johns Hopkins, within the past four years are not eligible for admission.

### MASTER'S DEGREE CANDIDATES

The program consists of ten courses planned in consultation with an advisor. General admission requirements for master's degree candidates are as follows: a bachelor's degree from a regionally accredited college or university (or have earned graduate degrees in technical disciplines), or in the last semester of undergraduate study; a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies (when reviewing an application, the candidate's academic and professional background will be considered.); a résumé detailing the applicant's professional background; official transcripts from all college studies; an application form submitted online; and any additional program-specific requirements.

After acceptance, each student is assigned an advisor with whom he or she jointly designs a program tailored to individual educational objectives.

Students must complete the master's degree within five years from the start of the first course in the program. Only one grade of C can count toward the master's degree.

## POST-MASTER'S CERTIFICATE CANDIDATES

To accommodate students who wish to pursue studies beyond the master's degree, many of the disciplines in the programs offer a certificate of post-master's study. This program is intended to add depth, breadth, or both in the discipline of the student's master's degree or a closely related one.

General admission requirements for post-master's certificate candidates are as follows: a master's degree in a relevant engineering or science discipline; official transcripts from all college studies; an application form submitted online; and any additional program-specific requirements.

After acceptance, each student is assigned an advisor with whom he or she jointly designs a program tailored to individual educational objectives.

Students must complete the post-master's certificate within three years of the first enrolling in the program. Only grades of B– or above can count toward the post-master's certificate.

## GRADUATE CERTIFICATE CANDIDATES

The graduate certificate is offered in a select number of degree disciplines and is directed toward students who may not need a master's degree, may not have the opportunity to pursue the entire master's degree, or may wish to focus their studies on a set of courses in a specific subject area. The certificate generally consists of five to six courses. The program area of study specifies the selection and number of applicable courses.

General admission requirements for graduate certificates candidates are as follows: a bachelor's degree from a regionally accredited college or university (or have earned graduate degrees in technical disciplines), or in the last semester of undergraduate study; a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies (when reviewing an application, the candidate's academic and professional background will be considered.); a résumé detailing the applicant's professional background; official transcripts from all college studies; an application form submitted online; and any additional program-specific requirements.

After acceptance, each student is assigned an advisor with whom he or she jointly designs a program tailored to individual educational objectives.

Students must complete the graduate certificate within three years of first enrolling in the program. Only grades of B– or above can count toward the graduate certificate.

## SPECIAL STUDENTS

Visiting graduate students are Special Students who are actively enrolled in graduate programs at other universities and are registering for Johns Hopkins Engineering for Professionals courses. They must be in good academic and disciplinary standing. If a Special Student later decides to apply for a degree, a letter of intent is required.

General admission requirements for Special Students are as follows: a bachelor's degree from a regionally accredited college or university (or have earned graduate degrees in technical disciplines), or in the last semester of undergraduate study; a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies (when reviewing an application, the candidate's academic and professional background will be considered.); a résumé detailing the applicant's professional background; official transcripts from all college studies; an application form submitted online; and any additional program-specific requirements.

## APPLICATION PROCEDURES

To be considered for admission to a degree or certificate program or to take courses as a Special Student, an applicant must submit an online application. The application is available online at ep.jhu.edu/apply. Complete instructions are available on the website.

An application for admission is not reviewed by an admissions committee until official transcripts from all colleges attended, a résumé detailing the applicant's professional background, and any additional required supporting documents are received. Please note that official transcripts must be received in the institution's sealed envelope or sent electronically via the Scrip-Safe network. Failure to provide all official transcripts, a résumé, and supporting documents, will delay review of the application. Please allow four to six weeks for application processing once all materials have been received.

## READMISSION

An application is held on file for one year from the date of its receipt. Applicants who fail to submit required materials within this period must reapply and submit another application and fee.

Applicants must satisfy admission requirements in force at the time of reapplication. Admitted students may defer the start of their studies for up to one year after admission. After one year of inactivity, the student must reapply.

Applicants who have been dismissed or suspended by any college or university, including Johns Hopkins, within the past four years are not eligible for admission.

## ADMISSION TO OTHER DIVISIONS OF THE UNIVERSITY

Any student who wishes to transfer to another school in the university or to a full-time engineering program must apply to the appropriate department or to the Office of Admissions. Admission to a Johns Hopkins Engineering for Professionals program establishes no claim or priority for admission to other divisions of the university.

## INTERNATIONAL APPLICANTS

The United States Immigration and Naturalization Service regulations require students with F-1 visas to be enrolled full-time in a degree-seeking program.

As Johns Hopkins Engineering for Professionals does not provide on-campus housing or financial support for graduate international students, applicants needing student F-1 visas must be able to present documented evidence of available financial support to cover annual living and educational expenses while studying at Johns Hopkins. Applicants who are in the United States on student visas should consult with their current schools' international offices for information on how to transfer to another approved school.

Johns Hopkins Engineering for Professionals is not authorized to certify the I-20 form required for a student visa. Those holding student visas granted by other universities are not allowed to register for classes and cannot be accepted as degree candidates or Special Students. For visa information, contact the Johns Hopkins Office of International Services at Homewood at oisss.jhu.edu.

## INTERNATIONAL CREDENTIAL EVALUATION

Applicants who hold degrees or have earned credits from non-US institutions must have their academic records evaluated by World Education Services, Inc. before they can be considered for graduate or Special Student status or admission to a degree/certificate program. In addition to submitting official records to Johns Hopkins Engineering for Professionals, applicants must make arrangements with the credential evaluation agency listed below for an evaluation of the degree, an assessment of the overall grade point average, and a course-by-course evaluation.

World Education Services, Inc.
P. O. Box 745
Old Chelsea Station
New York, NY 10113-0745
Telephone: 212-966-6311
Fax: 212-966-6395
E-mail: info@wes.org

## ENGLISH PROFICIENCY

Johns Hopkins requires students to have English proficiency for their courses of study. All international applicants must submit proof of their proficiency in English via the Test of English as a Foreign Language (TOEFL) or the International English Language Testing System (IELTS) before they can be offered admission.

A minimum score of 600 (paper-based), 250 (computer-based), or 100 (Internet-based) is required on the TOEFL; for the IELTS, an overall band score of at least 7.0 is required. The Johns Hopkins Engineering for Professionals admissions office requires official copies of all results.

## REQUESTS TO CHANGE PROGRAM OF STUDY

A student who wishes to change his/her status (e.g., from Special Student to master's degree candidate) or field of study (e.g., from Technical Management to Systems Engineering, or from the general Computer Science program to the Telecommunications and Networking concentration) must submit a written request to the Johns Hopkins Engineering for Professionals office. The student must meet all the admission requirements of the new program.

# REGISTRATION

Before registering for any engineering classes, each student must apply as a degree or certificate candidate or as a Special Student and must submit appropriate application materials for review. Application procedures are found in the Admission Requirements section on page 5. Applications are accepted on a continuing basis.

Payment of tuition is due at the specified deadline listed in the 2015–2016 Academic Calendar on page i. Payment may be made by check, credit card, tuition remission, or company contract accompanied by purchase order. Johns Hopkins Engineering for Professionals does not defer payment for companies providing tuition reimbursement at the end of the term. In this instance, students must pay tuition themselves and be reimbursed by their employers. If payment is not made by the deadline date, a late payment fee of $150 will be incurred.

If you have registered and have not paid your balance, an e-mail statement with the balance due to the university will be sent to you on the 16th of each month. This is not a bill. This is a reminder of the debt owed to the university and is a reflection of your account status at the time of the e-mail. Changes in circumstances, for instance, adding or dropping courses, late registration, or late payment fees, may have an effect on the amount that you are responsible to pay.

Students are not permitted to register if there are unpaid bills from a previous term.

## COURSE SCHEDULE

The Johns Hopkins Engineering for Professionals course schedule, which lists the day, time, location, and instructor for each course, is available on the web at ep.jhu.edu/schedule prior to each registration period. All students who have been enrolled in courses during the previous year will receive notification of the web posting of the course schedule. All relevant registration forms and deadlines can be found on the Johns Hopkins Engineering for Professionals website.

## COURSE NUMBERING SYSTEM

All Whiting School of Engineering courses are numbered in the form 605.402, where

- 605 indicates the program—in this example, Computer Science; and
- 402 indicates the course number—in this example, Software Analysis and Design.

Courses with a zero before the first decimal point—e.g., 600.439—are daytime offerings of the Whiting School of Engineering departments.

Courses numbered xxx.1xx, xxx.2xx, and xxx.3xx are undergraduate level and will not count for graduate credit.

## COURSE CREDIT

All courses 400 level and above earn three credit hours.

## NEW APPLICANTS

A new applicant may be approved to register for a class before a formal offer of admission is received. If the student is subsequently accepted to a degree or certificate program, the program committee will determine whether courses taken prior to admission may be counted in fulfillment of degree requirements. Please note that approval to take a course prior to receipt of an admission decision does not guarantee acceptance into the program. A student who has been granted approval to take a course before receiving an admissions decision must adhere to the published refund schedule. Refund exceptions will not be granted if the student is denied admission to the program.

## INTERDIVISIONAL REGISTRATION

With approval of their advisors, students may take courses in the full-time programs of the Whiting School of Engineering or in other divisions of the university. Registration for these classes should be submitted by e-mail to ep.registration@jhu.edu. Please note that tuition rates vary by division.

Students in other divisions of Johns Hopkins may register for Johns Hopkins Engineering for Professionals courses, subject to the regulations of their home divisions and availability of space.

## COURSE ENROLLMENT LIMITS

In order to foster high-quality faculty-student interaction, all courses have enrollment limits. Although every effort is made to offer additional sections of oversubscribed courses, this is not always possible.

Students may ask to be placed on waiting lists if their desired courses are filled, or they may indicate alternative course selections.

The university reserves the right to change instructors or to cancel any course with insufficient enrollment or for reasons beyond the control of the university.

## COURSE LOAD

Students who are employed full-time are advised not to take more than two courses per term without written permission from their employers.

## AUDITORS

Students may register as auditors with the approval of the appropriate program advisor. Although regular attendance is expected of auditors, they are exempt from quizzes, examinations, and other assigned work, and they receive no credit for the course. Students who are enrolled for credit but wish to become auditors must submit the "add/drop" form before the deadline listed for each term in the 2015–2016 Academic Calendar on page i. There is no reduction in fees when auditing a course.

### ADDING AND DROPPING COURSES

Courses may be added or dropped online at isis.jhu.edu. Deadlines for completing this procedure are given in the 2015–2016 Academic Calendar on page i. Notification to the instructor does not constitute dropping a course. Students who stop attending a course without completing and submitting the drop form will receive an F grade. The refund policy pertaining to dropped courses is described in the Tuition and Fees section on page 13.

### TEXTBOOKS

For textbook information, visit ep.jhu.edu/textbooks.

## ACADEMIC REGULATIONS

Following are the general requirements governing study in the Engineering for Professionals program at Johns Hopkins. Students are expected to be familiar with these requirements and with the specific regulations set forth in the sections relevant to particular programs of study.

Requirements for degree and certificate programs described in this catalog may change from time to time. When this occurs, students may fulfill either the requirements in force at the time of admission or those in force at the time of graduation.

### ADVISORS AND DEGREE AUDIT

Students are assigned an advisor when accepted. In addition, students are strongly encouraged to contact their advisors prior to registration. Logging of course and program completion as well as viewing of approvals and exceptions approved by a student's advisor can be tracked through degree audit viewable through ISIS.

### ACADEMIC STANDING

The university reserves the right to exclude, at any time, a student whose academic standing or general conduct is deemed unsatisfactory.

#### MASTER'S DEGREE CANDIDATES

Only one grade of C may be counted toward the master's degree.

**Academic Probation**—Any student receiving either one grade of F or two grades of C during their program of study will be placed on academic probation. Students placed on probation are permitted to retake any graduate course in which they have earned a grade of C or below. If a grade of B or above is earned in the repeated course, the probationary status will be removed. Please note that not all courses are offered every term. Students on probation who wish to retake a course will remain on probation until the course is offered again and completed with a grade of A or B. If an additional grade below B is received before the course is repeated and successfully completed, the student will be dismissed.

There are circumstances described below where students will not be placed on probation but will be immediately dismissed from the program.

**Academic Dismissal**—The following are causes for dismissal from the program:

- Students already on probation receiving an additional grade of C or below
- Students receiving a grade of C and a subsequent F
- Students receiving three grades of C
- Students receiving two grades of F
- Students receiving grades of F and C in the same term

Applicants who have been dismissed or suspended by any college or university, including Johns Hopkins, within the past four years are not eligible for admission.

#### POST-MASTER'S CERTIFICATE OR GRADUATE CERTIFICATE

No grade of C can be counted toward a graduate certificate or post-master's certificate. The above policy for probation and dismissal will apply.

#### SPECIAL STUDENTS

The above policy for probation and dismissal applies to Special Students.

### SECOND MASTER'S DEGREE

After receiving a master's degree from the programs, students may continue their graduate education in a second field if the appropriate prerequisites of the new program are fulfilled.

To receive a second master's degree, all requirements for the second program must be satisfied. If the following conditions are met, up to two courses taken as part of the first degree may be applied toward requirements of the second:

- The course(s) must satisfy the requirements of the second degree.
- The student's advisor must approve the course(s) as appropriate to the plan of study.
- The course(s) must fall within the five-year limit for the second degree; i.e., completion of the second degree must fall within five years from the date of the first class counted toward that degree.

## TIME LIMITATION

To be counted toward the degree or certificate, all course work in the program must be completed within a specified period, which begins with the start of the first course in the student's program:

- Master's degree: five years
- Post-master's certificate: three years
- Graduate certificate: three years

If necessary, a request for an extension, stating the extenuating circumstances, should be submitted in writing to the relevant program committee at least one semester before the student otherwise would be expected to graduate.

## LEAVE OF ABSENCE

Students who do not plan to enroll in classes for a period of one year or more must notify the Johns Hopkins Engineering for Professionals admissions office in writing and request a leave of absence for a specified period of time. The appropriate program chair will make the decision to approve or not approve the request.

Students who are granted a leave of absence must resume their studies at the end of the allotted leave time. If warranted, the time permitted to complete degree requirements will be extended by the length of time granted for the leave of absence. Students who do not resume their studies after a leave of absence has expired, or who have not enrolled for more than one year without having requested a leave of absence, will assume the status of a student who has withdrawn from the program. Such students must reapply and are subject to the admission requirements in force at the date of the new application. Acceptance is not guaranteed even for students previously admitted. Courses taken prior to the interruption of studies will not count toward requirements if they are not completed within the time allowed for degree completion.

## TRANSFERABILITY OF COURSES

Courses successfully completed through Johns Hopkins Engineering for Professionals may be transferred to other institutions. Transferability is solely at the discretion of the accepting institution.

## TRANSFER COURSES

Requests to transfer courses from another institution toward the master's degree will be considered on an individual basis. A maximum of two courses may be accepted for transfer to a master's degree or one course to a graduate or post-master's certificate with prior approval of the appropriate program chair. No request will be considered for courses taken more than five years prior to the start of the program. Courses must be graduate level, not previously applied toward an awarded degree, and directly applicable to the student's program of study at Johns Hopkins Engineering for Professionals. Requests should be submitted in writing to the admissions office at the Dorsey Student Services Center. Please include a course description. An official transcript showing the course to be transferred is required. To be official, the transcript must be received by the admissions office at the Dorsey Student Services Center in an institution's sealed envelope or electronically via the Scrip-Safe® network. Requests to transfer courses cannot be processed if the transcript is not official. The fee for transfer is $370 per course.

After being accepted into a Johns Hopkins Engineering for Professionals program of study, students may not take classes at another institution for transfer back to their Johns Hopkins Engineering for Professionals program. Courses successfully completed at Johns Hopkins Engineering for Professionals may be accepted for transfer credit at other institutions, but such transferability is solely at the discretion of the accepting institution.

## GRADUATION

Students who expect to receive a degree or certificate must submit an application for graduation. The graduation application should be submitted during the final term in which degree requirements will be completed. Instructions for completing the graduation application can be found by logging into ISIS and clicking on the program of study.

Students who are planning to graduate should complete all course work on time and should not request to receive the grade of I (incomplete) during their final semester.

Approximately two months after the semester begins, students who have submitted the application for graduation receive a preliminary letter stating that their names have been placed on the tentative graduation list for the semester in which they anticipate completing their degree requirements.

Commencement information is sent the first week in March. To receive their diplomas, students must pay all student accounts in full and resolve all outstanding charges of misconduct and violations of academic integrity. Students will receive an e-bill notification in the spring from Student Accounts. The e-bill will be sent to the student's preferred e-mail account. For graduation fees, see the Tuition and Fees section on page 13. Johns Hopkins University diplomas indicate the school (e.g., Whiting School of Engineering), degree, and major (e.g., Master of Science-Computer Science) without identifying the student's focus area/track.

## HONORS

Johns Hopkins Engineering for Professionals students will graduate with honors if they have earned an A+, A, or A– in all courses taken between admission and graduation from the degree program. Any other grade except a withdrawal or audit will disqualify students from receiving honors. The designation "Honors" will appear on student transcripts.

## GRADING SYSTEM

The following grades are used for the courses: A+, A, A– (excellent), B+, B, B– (good), C (unsatisfactory), F (failure), I (incomplete), W (official withdrawal), and AU (audit). The last two are not assigned by instructors.

A grade of F indicates the student's failure to complete or comprehend the course work. A course for which an unsatisfactory grade (C or F) has been received may be retaken. The original grade is replaced with an R. If the failed course includes laboratory, both the lecture and laboratory work must be retaken unless the instructor indicates otherwise. A grade of W is issued to those who have dropped the course after the refund period (the sixth class meeting for on-site courses) but before the drop deadline.

The transcript is part of the student's permanent record at the university. No grade may be changed except to correct an error, to replace an incomplete with a grade, or to replace a grade with an R.

The Whiting School assumes that students possess acceptable written command of the English language. It is proper for faculty to consider writing quality when assigning grades.

## INCOMPLETES

A grade of incomplete (I) is assigned when a student fails to complete a course on time for valid reasons, usually under circumstances beyond his or her control.

Conditions for resolving an incomplete are established by the instructor. A final grade must be submitted to the Registrar within four weeks after the start of the following term. A grade of F will be assigned if the incomplete work is not submitted by the deadline. For academic year 2015–2016, the dates by which final grades for incomplete work must be resolved are:

| | |
|---|---|
| Summer term | September 25 |
| Fall semester | February 19 |
| Spring semester | June 24 |

Students who expect to complete degree requirements but have an incomplete are not certified for graduation until the end of the following term.

## GRADE REPORTS

At the midpoint of each term, instructors are requested to provide a list of students whose work at that time is unsatisfactory. Students are notified by the Johns Hopkins Engineering for Professionals Student Services staff if their names are reported so they can take corrective action. These early reports are for the benefit of students and their advisors and are not part of the permanent record.

Grades are available online at isis.jhu.edu/sswf. These reports cannot be requested by telephone or personal inquiry. Students with questions regarding their grade reports or who want their transcripts sent to other institutions should make arrangements with the Office of the Registrar, 410-516-7088 or web.jhu.edu/registrar.

## GRADE APPEALS

A student's concerns regarding grades must be first discussed thoroughly with his or her instructor. If the student and the instructor are unable to reach an agreement, the student may appeal the instructor's decision, in writing, to the appropriate program chair, and, finally, to the associate dean. At each review level, evaluation criteria will be limited to (1) verification that there was not an error in recording the grade and (2) verification that the grade was determined on the basis of considered academic judgment. Grade appeals must be initiated within one semester after completing the course in question.

## STUDENT ATTENDANCE

Students are expected to regularly attend all courses in which they are enrolled. Although Johns Hopkins Engineering for Professionals and the university have no specific rules governing absences, the course instructor may announce certain attendance requirements. It is the student's responsibility to be aware of those requirements. Students who know they will be absent from class, especially for an extended period of time, should notify the instructor as far in advance as possible. It is the student's responsibility to discuss missed assignments and exams with the instructor. If an instructor is unavoidably late for class, the site office will attempt to notify students and tell them to wait, if it is practical. If an instructor is unable to meet a class, every attempt will be made by Johns Hopkins Engineering for Professionals staff to inform students of the cancellation, a makeup time for the class (if available), and information regarding assignments. If an instructor informs the Johns Hopkins Engineering for Professionals office of a class cancellation with enough lead time, phone calls will be made to students.

## ACADEMIC MISCONDUCT

This section summarizes the policy on academic misconduct described at engineering.jhu.edu/include/content/pdf-word/misconduct-policy.pdf.

### THE ROLES OF STUDENTS AND FACULTY

Johns Hopkins faculty and students have a joint responsibility to maintain the academic integrity of the university in all respects. Students must conduct themselves in a manner appropriate to the university's mission as an institution of higher education. Students are obligated to refrain from acts that they know, or under the circumstances have reason to know, impair the academic integrity of the university. Violations of academic integrity include, but are not limited to, cheating; plagiarism; unapproved multiple submissions; knowingly furnishing false information to any agent of the university for inclusion in academic records; and falsification, forgery, alteration, destruction, or misuse of official university documents.

Members of the faculty are responsible for announcing the academic requirements of each course, for the conduct of examinations, and for the security of examination papers and teaching laboratories. It is the duty of faculty to report suspected violations of academic integrity to the appropriate program chair. It is the responsibility of each student to report to the instructor any suspected violations of academic integrity.

### VIOLATIONS OF ACADEMIC INTEGRITY

After reviewing the circumstances of any suspected violation of academic integrity to determine whether a violation may have occurred, a program chair will promptly report (in writing) the suspected violation to the associate dean. Supporting evidence (e.g., copies of examination papers) should accompany the report. The associate dean will resolve the issues following the procedures set forth on the website noted above.

### COPYRIGHT VIOLATIONS

Copying, downloading, or distributing music, videos, software, games, or other copyrighted materials without permission of the owner violates both federal law and university policy and will be submitted for disciplinary action.

Original works fixed in any tangible medium of expression, which includes storage within computers, are copyrighted to the author from the moment of creation. No notice of copyright is required. Except under limited circumstances for limited purposes, you may not make or distribute copies of material belonging to others without their permission. Unless a site specifically grants you permission to download and copy material from the site, you should assume that you cannot do so. You should also assume that all person-to-person sharing of music, programs, videos, and software is a violation of copyright. Copyright violations will be submitted for disciplinary action.

## COMPUTER USAGE

Because Johns Hopkins University Office of Information Technology updates its policies frequently, please visit the Johns Hopkins University IT website at it.jhu.edu for the latest information on usage and security. The following includes key elements of the policy, which is posted in all Johns Hopkins Engineering for Professionals computer labs.

Acceptable use of IT resources is use that is consistent with Johns Hopkins' missions of education, research, service, and patient care and is legal, ethical, and honest; it must respect intellectual property, ownership of data, system security mechanisms, and individuals' rights to privacy and freedom from intimidation, harassment, and annoyance; it must show consideration in the consumption and utilization of IT resources; and it must not jeopardize Johns Hopkins' not-for-profit status. Incidental personal use of IT resources is permitted if consistent with applicable Johns Hopkins University and divisional policy, and if such use is reasonable, not excessive, and does not impair work performance or productivity.

Please visit it.jhu.edu for additional information on unacceptable use of IT resources.

# TUITION AND FEES

Students whose tuition is paid by contract should begin processing requests with their employers well before registration deadlines to ensure that payment is made as required. Students are ultimately responsible for all costs associated with their registration.

## TUITION

The graduate tuition fee is $3,710 per course, unless otherwise noted. The tuition for 200-level courses is $1,000. Tuition for courses in the daytime programs of the Whiting School is a percentage of full-time tuition. If students need a receipt for the classes they are attending, they may contact Student Accounts at 410-516-8158.

## GRADUATION FEE

The graduation fee is $100 and is payable upon receipt of an e-bill notification from the office of Student Accounts.

## LATE TUITION PAYMENT FEE

Tuition payment due dates are indicated in the 2015–2016 Academic Calendar on page i. If payment is received after the due date, a late payment fee of $150 will be incurred.

## TRANSFER CREDIT FEE

Graduate courses completed at another school and approved for transfer are assessed a fee of $370 per course.

## REFUND POLICY

Refunds apply only to the tuition portion of a student's charges and are calculated from the date of drop submission. Telephone drops or withdrawals are not accepted. Refunds are not applicable to any fees. Refunds are not granted to students who have been suspended or dismissed for disciplinary reasons. Tuition refunds are made in accordance with the following schedule.

| Drop Date | Refund |
|---|---|
| ***On-Site Courses*** | |
| Prior to third class meeting | 100% |
| Prior to fourth class meeting | 75% |
| Prior to fifth class meeting | 50% |
| Prior to sixth class meeting | 25% |
| ***Online Courses*** | |
| Prior to third week of class | 100% |
| Prior to fourth week of class | 75% |
| Prior to fifth week of class | 50% |
| Prior to sixth week of class | 25% |

Students who are enrolled at The Johns Hopkins University for the first time and who are receiving federal student financial aid are subject to a separate refund policy during their first period of enrollment. Refer to the Return of Title IV Funds Policy section on page 203 for further information.

# FINANCIAL AID

Federal financial aid in the form of student loans is available to part-time graduate degree candidates who are enrolled in two or more courses per term. Students must complete the Free Application for Federal Student Aid (FAFSA). This form is available online at fafsa.ed.gov. For more information about applying for financial aid, please review the Office of Student Financial Services website at jhu.edu/finaid or contact the Office of Student Financial Services, 146 Garland Hall, 410-516-8028, or fin_aid@jhu.edu.

## DEFINITION OF FULL-TIME, HALF-TIME, AND PART-TIME ENROLLMENT

Students who take three or more Johns Hopkins Engineering for Professionals courses each term are considered to be enrolled on a full-time basis, students who take two courses are considered to be enrolled on a half-time basis, and students who take one course are considered to be enrolled on a part-time basis.

## VETERANS BENEFITS

Johns Hopkins is approved by the Maryland Higher Education Commission for the training of veterans and the widows and children of deceased veterans under provisions of the various federal laws pertaining to veterans' educational benefits. Information about veterans' benefits and enrollment procedures may be obtained at the Registrar's Office, Garland Hall, 410-516-7071. Students eligible for veterans educational benefits register and pay their university bills in the same manner as other students. Reimbursement is made by the Department of Veterans Affairs (DVA) on a monthly basis. The amount of reimbursement is determined by the veteran's number of dependents and course load. Note that credits are not assigned to Johns Hopkins Engineering for Professionals graduate courses. A statement of "equivalent" credits for each graduate course taken may be obtained from the Registrar's Office. To obtain reimbursement, a veteran must comply with the following procedures:

**Initial Enrollment**—The veteran must first apply and be admitted to one of the schools of the university. He or she then obtains an Application for Program of Education or Training (DVA Form 22-1990) from the US Department of Veterans Affairs at gibill.va.gov.

After completing the application, the veteran sends it, with a certified copy of appropriate discharge papers, to the following address:

Johns Hopkins University
Office of the Registrar-75 Garland Hall
Veterans Affairs
3400 N. Charles Street
Baltimore, Maryland 21218-2681

**Transfers**—When transferring from another college or university, the veteran must obtain a Request for Change of Program or Place of Training Form (DVA Form 22-1995) from the US Department of Veterans Affairs at gibill.va.gov and submit the completed form to the Registrar's Office in Garland Hall at the university.

**Re-enrollment**—A student who received veterans benefits while attending the university during the preceding semester or summer session, and who plans to re-enroll with no change of objective, must advise the Registrar when submitting registration materials that he or she wishes to be re-certified under the provisions of the original DVA Form 22-1990.

Students receiving veterans benefits must pursue a program of courses that leads toward the exact objective (normally a degree or certificate) indicated on the original DVA application. Any change in program or objective requires submission of a Request for Change of Program (DVA Form 22-1995). Veteran students are required to advise the Registrar immediately of any change in their program or status (add/drops) that might affect the amount of their monthly payment from the DVA. Failure to do so will cause the DVA to seek restitution from the veteran for the overpayment of benefits.

**Standards of Progress**—Continuation of DVA payments is dependent on the veteran meeting the academic standards established by the university for all students—veterans and non-veterans alike. The veteran must also meet any standards of progress that are or may be established by DVA regulations. If the student fails to meet these standards, benefits will be suspended until the DVA completes a review of the student's progress and determines that the benefits may be resumed.

**Yellow Ribbon Tuition Assistance Program**—Johns Hopkins Engineering for Professionals participates in the Yellow Ribbon program provided by the US Department of Veterans Affairs to eligible veterans. For more specific information on applying for the Yellow Ribbon program at Johns Hopkins Engineering for Professionals, please contact the Registrar's Office at web.jhu.edu/registrar/veterans or 410-516-7071.

# FACILITIES AND STUDENT SERVICES

Johns Hopkins Engineering for Professionals courses are offered throughout Maryland at the Homewood campus in Baltimore; the Applied Physics Laboratory (APL) in Laurel; the Dorsey Student Services Center near Baltimore/Washington International Thurgood Marshall Airport; the Southern Maryland Higher Education Center in St. Mary's County; the University Center of Northeastern Maryland in Harford County; the Crystal City Center in Arlington, Virginia; Virtual Live; and online. The educational and student facilities and services provided at each location are described on the following pages.

## STUDENT ID JCARDS

The JCard acts as the university library card, which enables students to check out books from the Homewood Eisenhower Library or at any of the campus center libraries and provides access to many computer laboratories. To order or replace a lost or stolen JCard, contact the JCard Office at 410-516-5121

## TRANSCRIPTS

Official transcripts will be mailed at no charge on written request of the student. Requests for transcripts should be directed to the Office of the Registrar, 410-516-7088. Transcripts may also be ordered online, for a fee, from iwantmytranscript.com. For more information about each of these options, see web.jhu.edu/registrar/transcripts.

## INTERNATIONAL STUDENT SERVICES

For a description of all the services available at Johns Hopkins for international students, contact the Office of International Services at 410-516-1013 or jhu.edu/isss. For information related to Johns Hopkins Engineering for Professionals admission, please refer to the Admission Requirements section on page 5.

## SERVICES FOR STUDENTS WITH DISABILITIES

The Johns Hopkins University is committed to making all academic programs, support services, and facilities accessible to qualified individuals. Students with disabilities who require reasonable accommodations should contact the Johns Hopkins Engineering for Professionals Disability Support Services Coordinator at 410-516-2306 or e-mail ep-disability-svcs@jhu.edu.

To receive accommodations, students must provide the university a comprehensive evaluation of a specific disability from a qualified diagnostician that identifies the type of disability, describes the current level of functioning in an academic setting, and lists recommended accommodations. All documentation will be reviewed, and reasonable accommodations will be provided based on the student's needs. Students are encouraged to contact the Johns Hopkins Engineering for Professionals office at least six weeks prior to the beginning of each semester to ensure that services will be available.

For questions or concerns regarding university-wide disability issues, contact the Office of Institutional Equity (OIE) at web.jhu.edu/administration/jhuoie/disability/index.html.

## JH STUDENT ASSISTANCE PROGRAM

The Johns Hopkins Student Assistance Program (JHSAP) is a professional counseling service that can assist students with managing problems of daily living. Stress, personal problems, family conflict, and life challenges can affect the academic progress of students. JHSAP focuses on problem-solving through short-term counseling. Accessing the service is simple and requires only a phone call to arrange an appointment with a counselor. To meet the needs of our students, offices are conveniently located in the Washington/ Baltimore corridor. Online students may call one of the following numbers for consultation and will be directed to the appropriate resource or office. To contact JHSAP, call 443-997-7000 or toll-free 866-764-2317. Additional information regarding the JHSAP services can be obtained at jhsap.org. JHSAP services are completely confidential. The program operates under State and Federal confidentiality legislation and is HIPAA compliant.

## INCLEMENT WEATHER

The Johns Hopkins Weather Emergency Line can be reached at 410-516-7781 or 800-548-9004. The Johns Hopkins Weather Emergency Line provides information on campus closings due to inclement weather. The university may also use the same phone lines occasionally to distribute other urgent information. Announcements and closings will also be posted on the website at esgwebproxy.johnshopkins.edu/notice.

## WEB-BASED STUDENT DIRECTORY

Johns Hopkins Enterprise Directory (JHED) is the primary source for contact information of Johns Hopkins students. Your JHED login ID will be used for many web-based services, such as online registration, remote library access, and some course websites. You may find your login ID and initiate your account by going to my.jhu.edu from a computer at any of the campuses or by calling 410-516-HELP. Once you have set a password, you may use JHED from anywhere by logging in. If you have any questions, contact Hopkins Information Technology Services at 410-516-HELP.

## COMPUTERS

IT@Johns Hopkins (IT@JH) provides a number of resources that are useful to students. Brief descriptions are provided below. For more information, go to jumpstart.jhu.edu.

**Office 365 for Education**—Office 365 provides Johns Hopkins University students with a free 25-GB lifetime e-mail account; a 25-GB online storage solution; collaboration, blogging, photo sharing, event planning, and instant messaging tools; and more. Some features of Office 365 For Education include:

- Built-in protection and anytime/anywhere access
- A 25-GB e-mail account built on Outlook Live, permitting up to 20-MB attachments
- Easy access to e-mail from a variety of browsers on both the PC and Mac, including full support for Internet Explorer, Firefox, and Safari
- Connection to mailboxes using POP3, IMAP4 with preferred e-mail program or mobile phones
- Capabilities such as address books, calendars, mobile push e-mail, instant messaging, and more
- Improved collaboration and productivity, with ease of finding and sharing data and schedules from anywhere
- Ability to look up other users in the address book
- A single inbox to access all important communications

All students are required to activate their assigned Office 365 e-mail address. All official communications from Johns Hopkins Engineering for Professionals and Johns Hopkins University will be sent to this address, including class assignments, billing information, emergency notifications, and other important items. Visit it.johnshopkins.edu/services/email/Office365 to find instructions to activate your Office 365 e-mail address and to forward your Johns Hopkins University e-mail to other addresses.

**JHBox**—JHBox is a web-based utility intended to provide students with a personal, easy-to-use interface to upload, download, and share files to users both inside and outside of the institution. Some features of JHBox include

- 50 GB of FREE space per user
- Ease of uploading content, organizing documents, sharing links, managing files, and setting permissions
- Ability to designate files as private
- Version history for up to 90 days
- JHED ID login

Visit it.johnshopkins.edu/services/collaboration_tools/jhbox for more information.

**JHPulse**—JHPulse is a remote-access application that provides access to restricted Hopkins applications and systems when you are not on campus. JHPulse offers greater compatibility and support for newer computers and their operating systems.

Remote access to Hopkins is provided by JHPulse online through the myJH portal. More information about JHPulse is available at it.johnshopkins.edu/services/network/VPN.

*Note: You must have an active JHED login to access this site.*

**Anti-Virus Policy**—All devices vulnerable to electronic viruses must be appropriately safeguarded against infection and retransmission. It is the responsibility of every user to ensure that antivirus protection is current and effectively implemented. Infected devices may be blocked, removed, or both from the Johns Hopkins Network by IT@JH or appropriate departmental personnel. Visit it.johnshopkins.edu/antivirus to find the antivirus protection that is appropriate for your personal and Johns Hopkins University-owned computer.

## QUESTIONS AND GRIEVANCES

If you have a question or grievance that you would like to communicate to Johns Hopkins Engineering for Professionals, please e-mail jhep@jhu.edu.

# LOCATIONS

See the Directions and Maps section on page 207 for more information on the various Education Centers.

## APPLIED PHYSICS LABORATORY EDUCATION CENTER

The Applied Physics Laboratory (APL), a division of the Johns Hopkins University, is primarily a research and development organization. As such, a major part of its mission is the application of advanced science and technology in solving problems of national and global significance. However, its mission also includes support of the educational programs of the university, and it maintains strong academic relationships with the other university divisions.

One of APL's most significant educational contributions is its close collaboration with Johns Hopkins Engineering for Professionals. Chairs for ten of Johns Hopkins Engineering for Professionals' nineteen programs hold staff positions at APL, along with nearly half of Johns Hopkins Engineering for Professionals' instructors. APL provides classrooms, conference space, classroom computer labs, and UNIX/Linux servers for administrative and academic support of Johns Hopkins Engineering for Professionals in the Kossiakoff Center.

### COMPUTERS

Computer facilities at the Kossiakoff Center include Multi-User UNIX and Linux systems which support designated courses. Students can access these systems or the JHU network from their personal computers from either the wireless network within the Kossiakoff Center, or from their own personal network connections. The Engineering and Computing Lab and the Instructional Computer Lab provide support for general-purpose computing and applications development, embedded systems development and testing with state-of-the-art measurement equipment, interface design, and computer/network security.

### PARKING

Parking tags are not required. The lower-level parking lot near the Kossiakoff Center is recommended.

## CRYSTAL CITY CENTER

The Crystal City Center is Johns Hopkins Engineering for Professionals' first Northern Virginia center, located just south of the Pentagon and accessible via Metro's blue and yellow lines. Selected courses in systems engineering are currently offered on-site. The Johns Hopkins

University Whiting School of Engineering is certified to operate in the Commonwealth of Virginia by the State Council of Higher Education for Virginia.

## DORSEY STUDENT SERVICES CENTER

In addition to classrooms and computer labs, the Dorsey Center houses the admissions and registration staff and serves as a central point of access for academic advising and financial services. The Dorsey Center is located near the Baltimore/Washington International Thurgood Marshall Airport at 6810 Deerpath Road, Suite 100, Elkridge, MD.

The center has an instructional laboratory equipped with Sun Ray thin client workstations, personal computers, and high-speed Internet access. Access to the UNIX servers at APL is provided via dedicated high-speed lines. The Dorsey Center houses the Computer Robotics Lab, which allows students to develop computer-controlled autonomous robots. The center is also the site of 3D printer capabilities and the Johns Hopkins Engineering for Professionals' Microwave Engineering Laboratory, a state-of-the-art facility for designing, developing, and testing microwave chips and circuits. This laboratory houses a full variety of microwave testing and measurement equipment including:

- Network analyzers
- Spectrum analyzers
- Noise measuring equipment
- Sweep generators
- Synthesizers
- Fabrication and assembly equipment

In support of the microwave chip and circuit design process, our CAD laboratory has thirteen workstations (twelve for students and one for the instructor) offering the latest versions of following software:

- Creo Parametric and Pro/a list for mechanical engineering and analysis
- Agilent ADS, Sonnet, MATLAB, and gEE-CAD for microwave chip and circuit design and analysis
- CAD Capture and Layout for PCB design

These two laboratories offer our students the latest in hardware and software technology available in industry today.

## THE HOMEWOOD CAMPUS

The Homewood campus, located at 3400 North Charles Street in Baltimore, is grouped around two adjoining quadrangles. The Georgian architecture and wooded walkways and lawns make Homewood a pleasant retreat in a residential area of Baltimore.

### LIBRARIES

The entire library collection of Johns Hopkins University contains close to three million volumes; more than two million of these and one million microforms are available on the Homewood campus. Most of the Homewood collections are shelved in the Milton S. Eisenhower Library, which is open until 10 p.m. on Friday and Saturday and until midnight on the other days of the week.

After registering, students are issued a JCard by the JCard Office. This card entitles them to use the Eisenhower Library and the Hutzler Reading Room. Hours of operation can be found at library. jhu.edu/hours.html.

### TEXTBOOKS

Johns Hopkins Engineering for Professionals has selected MBS Direct as its single online textbook provider for all locations. MBS Direct also provides used books, buyback, a return policy, and a secure ordering site. Course textbooks can be found at ep.jhu.edu/textbooks or by clicking on the textbook icon for each individual course on the course schedule on the Johns Hopkins Engineering for Professionals website.

### JOHNS HOPKINS MERCHANDISE

Barnes & Noble Johns Hopkins sells apparel, gifts, school supplies, and books. For more information, call 410-662-5850 or visit johns-hopkins.bncollege.com.

### HOPKINS STUDENT UNION

Located in Levering Hall and the Glass Pavilion, the Hopkins Student Union offers various programs and activities for students, faculty, staff, and friends of the university. Levering Hall contains the Levering Food Court, a complete dining facility with various retail venues offering a combination of American and ethnic fare, and the Pura Vida Organic Coffee shop located in the Levering Lobby, offering gourmet coffee, sandwiches, and pastries. The hours of operation for all Homewood dining facilities are available at jhu.edu/hds/dining.

### SECURITY SERVICES

A daily escort van service is available during the hours of 5:00 p.m.–3:00 a.m. to pick up and deliver students to any campus parking lot or other location within a one-mile radius of campus. Vans leave every half hour from the Eisenhower Library.

Walking escorts are available by calling extension 8700 from any campus phone or 410-516-8700 from an outside or public telephone. Push-button security/escort phones, located in several campus buildings, can be used to alert security officers of an emergency, to request information, or to summon the escort van.

Emergency telephone stands with blue lights, which connect directly with the security office, are located at strategic locations around campus. These telephones open a direct line to the security office as soon as the receiver is lifted or the button pushed. To ward off a possible attacker, an alarm sounds at the phone. Pay telephones also are available in most campus buildings. Security officers patrol parking lots from 3:00–11:00 p.m., Monday through Friday. Student monitors, wearing bright orange vests and carrying radios, patrol the upper and lower quads during fall and spring semesters.

To reach the security office, call 410-516-4600. In the case of an emergency, call 410-516-7777.

### PARKING

Parking arrangements are made in the South Garage, under the Decker Quadrangle. Parking office hours are Monday through Friday, 7:30 a.m.–10:00 p.m., and Saturday through Sunday, 10:00 a.m.–6:30 p.m. Call 410-516-7275.

## SOUTHERN MARYLAND HIGHER EDUCATION CENTER

This facility was created by the Maryland General Assembly to serve as the regional upper-level undergraduate and graduate education and research institution for Southern Maryland. Currently, fourteen colleges and universities are participating, offering more than ninety-five academic programs, with more than eighty graduate and fifteen undergraduate completion programs. Facilities include two buildings with classrooms, a large multipurpose room, computer labs, a conference hall, a learning conference room, two student lounges, vending areas, and interactive videoconferencing capability. The full Systems Engineering and Technical Management programs are offered here, along with selected courses in Applied and Computational Mathematics.

## UNIVERSITY CENTER OF NORTHEASTERN MARYLAND

University Center is located in Harford County. Selected courses in Environmental Engineering, Environmental Engineering and Science, Environmental Planning and Management, Applied and Computational Mathematics, and Systems Engineering are currently being offered on-site.

# DEGREES AND CERTIFICATES OFFERED

| Program | Degree and Certificate | Focus Areas/Tracks | Locations | Online Offerings |
|---|---|---|---|---|
| **Applied Biomedical Engineering** | Master of Science in Applied Biomedical Engineering | ▪ Imaging<br>▪ Instrumentation<br>▪ Translational Tissue Engineering | ▪ Applied Physics Laboratory<br>▪ Dorsey Center<br>▪ Homewood Campus | **Can be Completed Online*** |
| | Post Master's Certificate | | | |
| **Applied and Computational Mathematics** | Master of Science in Applied and Computational Mathematics | ▪ Applied Analysis<br>▪ Information Technology and Computation<br>▪ Operations Research<br>▪ Probability and Statistics<br>▪ Simulation and Modeling | ▪ Applied Physics Laboratory<br>▪ Dorsey Center<br>▪ Southern Maryland Higher Education Center<br>▪ University Center of Northern Maryland | **Online Courses Available** |
| | Post Master's Certificate | | | |
| **Applied Physics** | Master of Science in Applied Physics | *CONCENTRATIONS*<br>▪ Materials and Condensed Matter<br>▪ Photonics | ▪ Applied Physics Laboratory<br>▪ Dorsey Center | **Online Courses Available** |
| | Post Master's Certificate | | | |
| **Chemical and Biomolecular Engineering** | Master of Chemical and Biomolecular Engineering | ▪ Biotechnology<br>▪ Nanotechnology | ▪ Homewood Campus | **Not Currently Available** |
| **Civil Engineering** | Master of Civil Engineering | ▪ Geotechnical Engineering<br>▪ Structural Engineering | ▪ Dorsey Center<br>▪ Homewood Campus | **Online Courses Available** |
| | Graduate Certificate | | | |
| **Climate Change, Energy, and Environmental Sustainability** | Post Master's Certificate | | | **Only Available Online** |
| **Computer Science** | Master of Science in Computer Science | ▪ Bioinformatics<br>▪ Cybersecurity<br>▪ Data Communications and Networking<br>▪ Data Science and Cloud Computing<br>▪ Database Systems and Knowledge Management<br>▪ Enterprise and Web Computing<br>▪ Human-Computer Interaction and Visualization<br>▪ Software Engineering<br>▪ Systems<br>▪ Theory<br>*CONCENTRATION*<br>▪ Telecommunications and Networking | ▪ Applied Physics Laboratory<br>▪ Dorsey Center | **Can be Completed Online** |
| | Post Master's Certificate | | | |

** Pending review and endorsement by the Maryland Higher Education Commission.*

| Program | Degree and Certificate | Focus Areas/Tracks | Locations | Online Offerings |
|---|---|---|---|---|
| Cybersecurity | Master of Science in Cybersecurity | ▪ Analysis<br>▪ Networks<br>▪ Systems | ▪ Applied Physics Laboratory<br>▪ Dorsey Center | Can be Completed Online |
| | Post Master's Certificate | | | |
| Electrical and Computer Engineering | Master of Science in Electrical and Computer Engineering | *CONCENTRATIONS*<br>▪ Photonics<br>▪ Telecommunications and Networking | ▪ Applied Physics Laboratory<br>▪ Dorsey Center | Can by Completed Online |
| | Post-Master's Certificate | | | |
| | Graduate Certificate | | | |
| Engineering Management | Master of Engineering Management | *CONCENTRATIONS*<br>▪ Applied and Computational Mathematics<br>▪ Applied Biomedical Engineering<br>▪ Applied Physics<br>▪ Communications, Controls, and Signal Processing<br>▪ Computer Engineering<br>▪ Computer Science<br>▪ Cybersecurity<br>▪ Geotechnical Engineering<br>▪ Information Systems Engineering<br>▪ Materials Science and Engineering<br>▪ Mechanical Engineering<br>▪ Optics and Photonics<br>▪ RF and Microwave Engineering<br>▪ Structural Engineering | ▪ Applied Physics Laboratory<br>▪ Dorsey Center | Online Courses Available |
| Environmental Engineering | Master of Environmental Engineering | | | Only Available Online |
| | Post-Master's Certificate | | | |
| | Graduate Certificate | | | |
| | *Dual-Degree*<br>Master of Environmental Engineering/ Master of Business Administration (*MBA not available online*) | | | |
| Environmental Engineering and Science | Master of Science in Environmental Engineering and Science | | | Only Available Online |
| | Post-Master's Certificate | | | |
| | Graduate Certificate | | | |
| | *Dual-Degree*<br>Master of Science in Environmental Engineering and Science/Master of Business Administration (*MBA not available online*) | | | |

| Program | Degree and Certificate | Focus Areas/Tracks | Locations | Online Offerings |
|---|---|---|---|---|
| Environmental Planning and Management | Master of Science in Environmental Planning and Management | | | Only Available Online |
| | Post-Master's Certificate | | | |
| | Graduate Certificate | | | |
| | *Dual Degree*<br>Master of Science in Environmental Planning and Management/Master of Business Administration (*MBA not available online*) | | | |
| | *Dual Degree*<br>Graduate Certificate in Environmental Planning and Management/ Master of Science in Applied Economics | | | |
| Information Systems Engineering | Master of Science in Information Systems Engineering | ▪ Cybersecurity<br>▪ Enterprise and Web Computing<br>▪ Human-Computer Interaction<br>▪ Information Management<br>▪ Network Engineering<br>▪ Software Engineering<br>▪ Systems Engineering | ▪ Applied Physics Laboratory<br>▪ Dorsey Center | Can be Completed Online |
| | Post-Master's Certificate | | | |
| | Graduate Certificate | | | |
| Materials Science and Engineering | Master of Materials Science and Engineering | ▪ Biotechnology<br>▪ Nanomaterials<br>*CONCENTRATION*<br>▪ Nanotechnology | ▪ Applied Physics Laboratory<br>▪ Dorsey Center<br>▪ Homewood Campus | Not Currently Available |
| Mechanical Engineering | Master of Mechanical Engineering | ▪ Manufacturing<br>▪ Mechanics: Solids or Thermofluids<br>▪ Robotics and Controls | ▪ Applied Physics Laboratory<br>▪ Dorsey Center<br>▪ Homewood Campus | Online Courses Available |
| | Post-Master's Certificate | | | |
| Space Systems Engineering | Master of Science in Space Systems Engineering | | ▪ Applied Physics Laboratory | Online Courses Available |
| Systems Engineering | Master of Science in Systems Engineering<br>Master of Science in Engineering in Systems Engineering | ▪ Biomedical Systems Engineering<br>▪ Human Systems Engineering<br>▪ Information Assurance Systems Engineering<br>▪ Modeling and Simulation Systems Engineering<br>▪ Project Management<br>▪ Software Systems Engineering<br>▪ Systems Engineering | ▪ Applied Physics Laboratory<br>▪ Crystal City Center<br>▪ Dorsey Center<br>▪ Southern Maryland Higher Education Center<br>▪ University Center of Northern Maryland | Can be Completed Online |
| | Graduate Certificate | | | |
| | Post-Master's Certificate | | | |
| Technical Management | Master of Science in Technical Management | ▪ Organizational Management<br>▪ Project Management<br>▪ Project/Organizational Management<br>▪ Quality Management<br>▪ Technical Innovation Management | ▪ Applied Physics Laboratory<br>▪ Dorsey Center | Can be Completed Online |
| | Graduate Certificate | | | |
| | Post-Master's Certificate | | | |

# APPLIED BIOMEDICAL ENGINEERING

- **Master of Science in Applied Biomedical Engineering**
  *Focus Areas*: Imaging, Instrumentation, or Translational Tissue Engineering*
- **Post-Master's Certificate in Applied Biomedical Engineering**

The part-time Applied Biomedical Engineering program aims to educate and train practicing scientists and engineers to be able to carry out engineering-oriented research and development in the biomedical sciences. In addition to diverse student backgrounds, the program's most valuable strength lies in the active faculty currently involved in research and development.

Courses are offered at the Applied Physics Laboratory, the Dorsey Center, Homewood campus, and online. Various electives are offered through the full-time Department of Biomedical Engineering and the School of Medicine.

## PROGRAM COMMITTEE

EILEEN HAASE, PROGRAM CHAIR
Senior Lecturer, Biomedical Engineering JHU, Whiting School of Engineering

BROCK WESTER, VICE PROGRAM CHAIR
Senior Professional Staff, JHU Applied Physics Laboratory

MURRAY B. SACHS
Principal Professional Staff, JHU Applied Physics Laboratory

Professor Emeritus, Johns Hopkins School of Medicine

LARRY SCHRAMM
Professor of Biomedical Engineering, Johns Hopkins School of Medicine

ARTIN SHOUKAS
Professor Emeritus, Johns Hopkins School of Medicine

LESLIE TUNG
Professor of Biomedical Engineering, Johns Hopkins School of Medicine

*A focus area must be chosen for this program.*

# REQUIREMENTS

## MASTER OF SCIENCE

### ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include (1) mathematics, through ordinary differential equations; (2) calculus-based physics, including mechanics, heat and energy, electricity and magnetism, and elementary quantum concepts; (3) chemistry; and (4) molecular biology. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

Courses in organic chemistry, molecular biology, mathematics, and Signals & Systems are offered for those who may need them to satisfy the eligibility requirements or to refresh their knowledge.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students are required to choose a focus area to follow. The curriculum consists of five core courses (one from the focus area), at least one additional course from the focus area, and four electives (at least four of the ten courses must be at the 600-level or higher). One elective may be substituted for a required course if the student has previously completed an equivalent graduate-level course, or can demonstrate competency. Electives may be from the Applied Biomedical Engineering (585.xxx) program, or from the Department of Biomedical Engineering (580.xxx) in the full-time program and the Zanvyl Krieger School of Arts and Sciences' Advanced Academic Programs (410.xxx). All course selections are subject to advisor approval.

## POST-MASTER'S CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post Master's Certificate in Applied Biomedical Engineering.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least five of the six courses must be from the Applied Biomedical Engineering (585.xxx) program, and at least two of the courses must be at the 600-level. Students are allowed to take one elective course. Courses from the full-time program and/or medical school (580.xxx) may be substituted. Only grades of B- and above may count toward the post-master's certificate. Focus areas are not available for students pursing certificates. All course selections are subject to advisor approval.

# COURSES

## PREREQUISITE COURSES

585.209 Organic Chemistry
585.207 Molecular Biology *OR*
 410.602 Molecular Biology*
625.201 General Applied Mathematics

*These courses do not count towards degree or certificate requirements.*

## CORE COURSES

585.405 Physiology for Applied Biomedical Engineering I
585.406 Physiology for Applied Biomedical Engineering II
585.409 Mathematical Methods for Applied Biomedical Engineering *OR*
 535.441 Mathematical Methods for Engineers
585.425 Biomedical Engineering Practice and Innovation

*See below for the fifth core course, which is specific to each focus area.*

## COURSES BY FOCUS AREAS

The focus areas offered represent related groups of courses that are relevant for students with interests in the selected areas. Students are required to choose a focus area to follow. The focus areas are presented as an aid to students in planning their course schedules and are only applicable to students seeking a master's degree. They do not appear as official designations on a student's transcript or diploma.

### IMAGING

*CORE COURSE (SELECT ONE)*

585.604 Principles of Medical Imaging
585.605 Medical Imaging

*OTHER COURSES FOR THE FOCUS AREA (SELECT AT LEAST ONE)*

585.411 Principles of Medical Instrumentation and Devices
585.423 Systems Bioengineering Lab I (1/2 credit)
585.424 Systems Bioengineering Lab II (1/2 credit)
585.606 Medical Image Processing
585.607 Medical Imaging II: MRI
585.610 Biochemical Sensors
585.631 Advanced Signal Processing for Biomedical Engineers
585.633 Biosignals
585.800 Special Project in Applied Biomedical Engineering

** This course is offered online through the Zanvyl Krieger School of Arts and Sciences' Advanced Academic Programs)*

## INSTRUMENTATION

*CORE COURSE (SELECT ONE)*

585.408 Medical Sensors and Devices

585.411 Principles of Medical Instrumentation and Devices

*OTHER COURSES FOR THE FOCUS AREA (SELECT AT LEAST ONE)*

585.414 Rehabilitation Engineering

585.423 Systems Bioengineering Lab I (1/2 credit)

585.424 Systems Bioengineering Lab II (1/2 credit)

585.605 Medical Imaging

585.606 Medical Image Processing

585.607 Medical Imaging II: MRI

585.610 Biochemical Sensors

585.624 Neural Prosthetics: Science, Technology, and Applications

585.631 Advanced Signal Processing for Biomedical Engineers

585.633 Biosignals

585.634 Biophotonics

585.800 Special Project in Applied Biomedical Engineering

## TRANSLATIONAL TISSUE ENGINEERING

*CORE COURSE*

585.629 Cell and Tissue Engineering

*OTHER COURSES FOR THE FOCUS AREA (SELECT AT LEAST ONE)*

585.414 Rehabilitation Engineering

585.423 Systems Bioengineering Lab I (1/2 credit)

585.424 Systems Bioengineering Lab II (1/2 credit)

585.608 Biomaterials

585.609 Cell Mechanics

585.610 Biochemical Sensors

585.618 Biological Fluid and Solid Mechanics

585.620 Orthopedic Biomechanics

585.624 Neural Prosthetics: Science, Technology, and Applications

585.800 Special Project in Applied Biomedical Engineering

## ELECTIVES

The following electives are offered during the day through the full-time Department of Biomedical Engineering at the Homewood campus or at the School of Medicine.

580.420 Build-a-Genome

580.448 Biomechanics of the Cell

580.451 Cellular and Tissue Engineering Laboratory

580.452 Cellular and Tissue Engineering Laboratory

580.466 Statistical Methods in Imaging

580.488 Foundations of Computational Biology and Bioinformatics II

580.495 Microfabrication Laboratory

580.616 Introduction to Linear Systems

580.625 Structure and Function of the Auditory and Vestibular Systems

580.626 Structure and Function of the Auditory and Vestibular Systems

580.628 Topics in Systems Neuroscience

580.630 Theoretical Neuroscience

580.632 Ionic Channels in Excitable Membranes

580.634 Molecular and Cellular Systems Physiology Laboratory

580.639 Models of the Neuron

580.641 Cellular Engineering

580.642 Tissue Engineering

580.673 Magnetic Resonance in Medicine

580.677 Advanced Topics in Magnetic Resonance

580.682 Computational Models of the Cardiac Myocyte

580.684 Ultrasound Imaging: Theory and Applications

580.688 Foundations of Computation Biology and Bioinformatics II

580.691 Learning Theory

580.771 Principles of Design of Biomedical Instrumentation

***For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.***

***Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.***

# APPLIED AND COMPUTATIONAL MATHEMATICS

- **Master of Science in Applied and Computational Mathematics**
  *Focus Areas*: Applied Analysis, Information Technology and Computation, Operations Research, Probability Statistics, and Simulation and Modeling
- **Post-Master's Certificate in Applied and Computational Mathematics**

The part-time Applied and Computational Mathematics program prepares working professionals through instruction in mathematical and computational techniques that are fundamentally important and practically relevant. Students choose from one of five focus areas, or have the option of tailoring their courses to meet individual needs.

Courses are offered at the Applied Physics Laboratory, the Dorsey Center, Southern Maryland Higher Education Center, University Center of Northeastern Maryland, and online.

## PROGRAM COMMITTEE

JAMES C. SPALL, PROGRAM CHAIR
Principal Professional Staff, JHU Applied Physics Laboratory

Research Professor, Department of Applied Mathematics and Statistics, JHU Whiting School of Engineering

BERYL CASTELLO
Senior Lecturer, Applied Mathematics and Statistics, JHU Whiting School of Engineering

STACY D. HILL
Senior Professional Staff, JHU Applied Physics Laboratory

GEORGE NAKOS
Professor, Mathematics US Naval Academy

EDWARD R. SCHEINERMAN
Professor, Applied Mathematics and Statistics

Vice Dean for Education, JHU Whiting School of Engineering

J. MILLER WHISNANT
Principal Professional Staff, JHU Applied Physics Laboratory

# REQUIREMENTS

## MASTER OF SCIENCE

### ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include at least one mathematics course beyond multivariate calculus (such as advanced calculus, differential equations, or linear algebra) and familiarity with at least one programming language (e.g., C, C++, FORTRAN, Java, Python, or MATLAB). Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

Undergraduate courses are offered to provide mathematical background for the program. These 200-level courses are not for graduate credit. Some students may find one or more of these courses useful as a refresher or to fill gaps in their training.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of four core courses (including a two-term course) and six electives. The six electives must include at least four from the program (625.xxx), with at least two of the four courses at the 700-level. Students are required to take at least one 700-level course outside of the core sequences (625.717/718, 625.721/722, and 625.725/726). A student who has taken at least one year of undergraduate statistics or one semester of graduate statistics (outside of Applied and Computational Mathematics) may substitute another 625.xxx course for 625.403 with approval of the student's advisor. Focus areas are not required for this program. Only one grade of C may count toward the master's degree. All course selections are subject to advisor approval.

## POST-MASTER'S CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in applied and computational mathematics or a closely related technical discipline are eligible to apply for the Post Master's Certificate in Applied and Computational Mathematics. It is expected that applicants will have completed courses equivalent to 625.403 Statistical Methods and Data Analysis, and at least 625.401 Real Analysis or 625.409 Matrix Theory in prior graduate coursework.

Students with long-standing interest in pursuing PhDs through the Applied Mathematics and Statistics (AMS) Department in the full-time program should coordinate their course plans with their Applied and Computational Mathematics advisor and with a representative in the AMS Department. Certain courses within Applied and Computational Mathematics may be especially helpful in passing the required entrance examination for the PhD program. Priority of admission is not given to graduates of the Applied and Computational Mathematics program for the PhD program.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least four of the six courses must be from the Applied and Computational Mathematics program (numbered 625.480 or higher). At least three of the courses must be at the 700-level, and at least one of the 700-level courses must be outside of the sequences 625.717/718, 625.721/722, and 625.725/726. Students are allowed to take one mathematically oriented elective course from outside the program. Courses 625.401 Real Analysis, 625.403 Statistical Methods and Data Analysis, and 625.409 Matrix Theory may not be counted. Only grades of B- or above can count toward the post-master's certificate. Focus areas are not available for students pursing certificates. All course selections are subject to advisor approval.

# COURSES

## PREREQUISITE COURSES

625.201 General Applied Mathematics

625.250 Applied Mathematics I

625.251 Applied Mathematics II

625.260 Introduction to Linear Systems

*These courses do not count towards degree or certificate requirements.*

*See page 82 for course descriptions.*

## CORE COURSES

625.403 Statistical Methods and Data Analysis

625.401 Real Analysis *OR*
625.409 Matrix Theory

***SELECT ONE SEQUENCE***

625.717 Advanced Differential Equations: Partial Differential Equations *AND*
625.718 Advanced Differential Equations: Nonlinear Differential Equations and Dynamical Systems

625.721 Probability and Stochastic Processes I *AND*
625.722 Probability and Stochastic Processes II

625.725 Theory of Statistics I *AND*
625.726 Theory of Statistics II

## COURSES BY FOCUS AREAS

The focus areas offered represent related groups of courses that are relevant for students with interests in the selected areas. The focus areas are presented as an aid to students in planning their course schedules and are only applicable to students seeking a master's degree. Focus areas are not required for this program. They do not appear as official designations on a student's transcript or diploma.

### APPLIED ANALYSIS

625.401 Real Analysis
625.402 Modern Algebra
625.404 Ordinary Differential Equations
625.409 Matrix Theory
625.411 Computational Methods
625.480 Cryptography
625.485 Number Theory
625.487 Applied Topology
625.490 Computational Complexity and Approximation
625.703 Functions of a Complex Variable
625.710 Fourier Analysis with Applications to Signal Processing and Differential Equations
625.717 Advanced Differential Equations: Partial Differential Equations
625.718 Advanced Differential Equations: Nonlinear Differential Equations and Dynamical Systems
625.728 Theory of Probability

### INFORMATION TECHNOLOGY AND COMPUTATION

625.403 Statistical Methods and Data Analysis
625.409 Matrix Theory
625.411 Computational Methods
625.414 Linear Optimization
625.415 Nonlinear Optimization
625.417 Applied Combinatorics and Discrete Mathematics
625.423 Introduction to Operations Research: Probabilistic Models
625.438 Neural Networks
625.461 Statistical Models and Regression
625.468 Statistical Privacy Protection in Large Datasets
625.480 Cryptography
625.485 Number Theory
625.487 Applied Topology
625.490 Computational Complexity and Approximation
625.495 Time Series Analysis and Dynamic Modeling
625.725 Theory of Statistics I
625.726 Theory of Statistics II
625.734 Queuing Theory with Applications to Computer Science
625.740 Data Mining
625.743 Stochastic Optimization and Control
625.744 Modeling, Simulation, and Monte Carlo

### OPERATIONS RESEARCH

625.403 Statistical Methods and Data Analysis
625.409 Matrix Theory
625.414 Linear Optimization
625.415 Nonlinear Optimization
625.417 Applied Combinatorics and Discrete Mathematics
625.423 Introduction to Operations Research: Probabilistic Models
625.436 Graph Theory
625.441 Mathematics of Finance: Investment Science
625.442 Mathematics of Risk, Options, and Financial Derivatives
625.461 Statistical Models and Regression
625.462 Design and Analysis of Experiments
625.463 Multivariate Statistics and Stochastic Analysis
625.490 Computational Complexity and Approximation
625.495 Time Series Analysis and Dynamic Modeling
625.714 Introductory Stochastic Differential Equations with Applications
625.721 Probability and Stochastic Process I
625.722 Probability and Stochastic Process II
625.725 Theory of Statistics I
625.726 Theory of Statistics II
625.734 Queuing Theory with Applications to Computer Science
625.740 Data Mining
625.741 Game Theory
625.743 Stochastic Optimization and Control
625.744 Modeling, Simulation, and Monte Carlo

### PROBABILITY AND STATISTICS

625.403 Statistical Methods and Data Analysis
625.417 Applied Combinatorics and Discrete Mathematics
625.420 Mathematical Methods for Signal Processing
625.423 Introduction to Operations Research: Probabilistic Models
625.438 Neural Networks
625.441 Mathematics of Finance: Investment Science
625.442 Mathematics of Risk, Options, and Financial Derivatives
625.461 Statistical Models and Regression
625.462 Design and Analysis of Experiments
625.463 Multivariate Statistics and Stochastic Analysis
625.464 Computational Statistics
625.480 Cryptography
625.490 Computational Complexity and Approximation
625.492 Probabilistic Graphical Models
625.495 Time Series Analysis and Dynamic Modeling
625.710 Fourier Analysis with Applications to Signal Processing and Differential Equations

625.714 Introductory Stochastic Differential Equations with Applications
625.721 Probability and Stochastic Process I
625.722 Probability and Stochastic Process II
625.725 Theory of Statistics I
625.726 Theory of Statistics II
625.728 Theory of Probability
625.734 Queuing Theory with Applications to Computer Science
625.740 Data Mining
625.741 Game Theory
625.743 Stochastic Optimization and Control
625.744 Modeling, Simulation, and Monte Carlo

## SIMULATION AND MODELING

625.403 Statistical Methods and Data Analysis
625.404 Ordinary Differential Equations
625.414 Linear Optimization
625.415 Nonlinear Optimization
625.420 Mathematical Methods for Signal Processing
625.423 Introduction to Operations Research: Probabilistic Models
625.438 Neural Networks
625.441 Mathematics of Finance: Investment Science
625.442 Mathematics of Risk, Options, and Financial Derivatives
625.461 Statistical Models and Regression
625.462 Design and Analysis of Experiments
625.463 Multivariate Statistics and Stochastic Analysis
625.464 Computational Statistics
625.490 Computational Complexity and Approximation
625.495 Time Series Analysis and Dynamic Modeling
625.714 Introductory Stochastic Differential Equations with Applications
625.717 Advanced Differential Equations: Partial Differential Equations
625.718 Advanced Differential Equations: Nonlinear Differential Equations and Dynamical Systems
625.721 Probability and Stochastic Process I
625.722 Probability and Stochastic Process II
625.725 Theory of Statistics I
625.726 Theory of Statistics II
625.728 Theory of Probability
625.740 Data Mining
625.741 Game Theory
625.743 Stochastic Optimization and Control
625.744 Modeling, Simulation, and Monte Carlo

## ELECTIVES

Two electives may be from the program or from another graduate program provided the courses have significant mathematical content. Electives from outside of the program must be approved by an advisor.

*For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.*

*Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.*

# APPLIED PHYSICS

- **Master of Science in Applied Physics**
  *Concentrations*: Materials and Condensed Matter or Photonics
- **Post-Master's Certificate in Applied Physics**

The part-time Applied Physics program bridges the gap between pure physics and engineering by conducting research on technical applications of natural phenomena. Working professionals develop skills appropriate for their careers in technical research or advanced graduate study. One of the program's strengths is its faculty, who are primarily drawn from the Johns Hopkins Applied Physics Laboratory. Faculty interests are in materials, ocean sciences, optics, solid-state physics, and space sciences.

Courses are offered at the Applied Physics Laboratory and the Dorsey Center.

## PROGRAM COMMITTEE

HARRY K. CHARLES JR., PROGRAM CHAIR
Principal Professional Staff, JHU Applied Physics Laboratory

ROBERT C. CAMMARATA
Professor, Materials Science and Engineering, JHU Whiting School of Engineering

DAVID L. PORTER
Principal Professional Staff, JHU Applied Physics Laboratory

ABIGAIL M. RYMER
Senior Professional Staff, JHU Applied Physics Laboratory

JENNIFER L. SAMPLE
Principal Professional Staff, JHU Applied Physics Laboratory

JOSEPH J. SUTER
Principal Professional Staff, JHU Applied Physics Laboratory

MICHAEL E. THOMAS
Principal Professional Staff, JHU Applied Physics Laboratory

# REQUIREMENTS

## MASTER OF SCIENCE

### ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to a graduate to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include (1) mathematics through vector analysis and ordinary differential equations; (2) general physics, (3) modern physics, (4) intermediate mechanics; and (5) intermediate electricity and magnetism. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

The intermediate mechanics and intermediate electricity and magnetism requirements may be waived if the applicant has an exceptionally good grade-point average and a strong background in mathematics.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of four core courses and six electives. At least four of the courses must be at the 700-level or higher. An elective may be substituted for a required course if the student has previously completed an equivalent graduate-level course. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

*CONCENTRATIONS*

*MATERIALS AND CONDENSED MATTER*

Students can elect to concentrate their studies in materials and condensed matter by completing a combination of courses from the Applied Physics (615.xxx), Electrical and Computer Engineering (525.xxx), and Materials Science and Engineering (515.xxx) programs. Applied Physics students specializing in materials and condensed matter must complete three of the core courses plus 615.480 Materials Science.

Of the remaining six courses, four or more must be materials and condensed matter courses selected from the Applied Physics (615.xxx), Electrical and Computer Engineering (525.xxx), and Materials Science and Engineering (515.xxx) programs. All course selections are subject to advisor approval.

Concentrations are noted on the student's transcript.

*PHOTONICS*

Three Applied Physics core courses (615.xxx), one Electrical and Computer Engineering core course (525.xxx), four Photonics electives, and two electives from the program. All course selections are subject to advisor approval.

Concentrations are noted on the student's transcript.

## POST-MASTER'S CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post Master's Certificate in Applied Physics.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least four of the six courses must be from the Applied Physics program (615.xxx), and at least two of the courses must be at the 700-level. Students are allowed to take two electives (at least one must be at the 700-level). Only grades of B- or above can count toward the post-master's certificate. All course selections are subject to advisor approval.

# COURSES

## CORE COURSES

*SELECT FOUR (AT LEAST THREE MUST BE FROM THE FIRST SIX)*

615.441 Mathematical Methods for Physics and Engineering
615.442 Electromagnetics
615.451 Statistical Mechanics and Thermodynamics
615.453 Classical Mechanics
615.454 Quantum Mechanics
615.465 Modern Physics
615.471 Principles of Optics
615.480 Materials Science

## ELECTIVES

*SELECT SIX*

615.421 Electric Power Principles
615.444 Fundamentals of Space Systems I
615.445 Fundamentals of Space Systems II
615.446 Physics of Magnetism
615.447 Fundamentals of Sensors
615.448 Alternate Energy Technology
615.462 Introduction to Astrophysics
615.481 Polymeric Materials
615.731 Photovoltaic and Solar Thermal Energy
615.746 Nanoelectronics: Physics and Devices
615.747 Sensors and Sensor Systems
615.748 Introduction to Relativity
615.751 Modern Optics
615.753 Plasma Physics
615.755 Space Physics
615.757 Solid-State Physics
615.758 Modern Topics in Applied Optics
615.760 Physics of Semiconductor Devices

615.761 Introduction to Oceanography
615.762 Applied Computational Electromagnetics
615.765 Chaos and Its Applications
615.769 Physics of Remote Sensing
615.772 Cosmology
615.775 Physics of Climate
615.778 Computer Optical Design
615.780 Optical Detectors and Applications
615.781 Quantum Information Processing
615.782 Optics and MATLAB
615.800 Applied Physics Project
615.802 Directed Studies in Applied Physics Conversion

# COURSES BY CONCENTRATION

## MATERIALS AND CONDENSED MATTER

*FOUR CORE COURSES*

615.441 Mathematical Methods for Physics and Engineering
615.442 Electromagnetics
615.451 Statistical Mechanics and Thermodynamics
615.480 Materials Science

*ELECTIVES (SELECT AT LEAST FOUR)*

510.604 Mechanical Properties of Materials*
510.606 Chemical and Biological Properties of Materials*
515.417 Nanomaterials
525.406 Electronic Materials
525.421 Introduction to Electronics and the Solid State I
615.446 Physics of Magnetism
615.447 Fundamentals of Sensors
615.481 Polymeric Materials
615.746 Nanoelectronics: Physics and Devices
615.747 Sensors and Sensor Systems
615.757 Solid-State Physics
615.760 Physics of Semiconductor Devices

*615.800 Applied Physics Project and 615.802 Directed Studies in Applied Physics can also be used to allow the student to pursue specialized interests in Materials Science and Condensed Matter.*

## PHOTONICS

*FOUR CORE COURSES (ONLY ONE 525.XXX COURSE IS REQUIRED)*

525.413 Fourier Techniques in Optics
525.425 Laser Fundamentals
525.491 Fundamentals of Photonics
615.441 Mathematical Methods for Physics and Engineering
615.454 Quantum Mechanics
615.471 Principles of Optics

*ELECTIVES (SELECT AT LEAST FOUR)*

525.413 Fourier Techniques in Optics
525.425 Laser Fundamentals
525.436 Optics and Photonics Laboratory
525.491 Fundamentals of Photonics
525.753 Laser Systems and Applications
525.756 Optical Propagation, Sensing, and Backgrounds
525.772 Fiber-Optic Communication Systems
525.792 Electro-Optical Systems
525.796 Introduction to High-Speed Electronics and Optoelectronics
525.797 Advanced Optics and Photonics Laboratory
615.751 Modern Optics
615.758 Modern Topics in Applied Optics
615.778 Computer Optical Design
615.780 Optical Detectors and Applications
615.781 Quantum Information Processing
615.782 Optics and MATLAB

*615.800 Applied Physics Project and 615.802 Directed Studies in Applied Physics can also be used to allow the student to pursue specialized interests in Optics.*

***For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.***

***Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.***

** 510.xxx courses are offered through the full-time Department of Materials Science & Engineering*

# CHEMICAL AND BIOMOLECULAR ENGINEERING

- **Master of Chemical and Biomolecular Engineering**
  *Focus Areas*: Biotechnology or Nanotechnology

The part-time Chemical and Biomolecular Engineering program allows working professionals to choose from two focus areas, or to study a more traditional curriculum that is supplemented with electives from related engineering fields, the basic sciences, or mathematics. The program offers a professional, non-thesis curriculum for working engineers, but is also suited for those with a science background who are taking their career in a new direction.

Courses are offered at the Homewood campus. Various electives are offered through the full-time Department of Chemical & Biomolecular Engineering.

## PROGRAM COMMITTEE

**MICHAEL BETENBAUGH, PROGRAM CHAIR**
Professor, Chemical and Biomolecular Engineering, Whiting School of Engineering

**SANKAR RAGHAVAN, PROGRAM COORDINATOR**
Instructor, Chemical and Biomolecular Engineering, Whiting School of Engineering

**KONSTANTINOS KONSTANTOPOULOS**
Department Chair, Chemical and Biomolecular Engineering, Whiting School of Engineering

# REQUIREMENTS

## MASTER'S

### ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include (1) a bachelor's degree in chemical engineering, or a closely related technical or scientific discipline; (2) mathematics through differential and integral calculus and differential equations; and (3) course work in physical chemistry and thermodynamics. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

Non-chemical engineering majors must complete additional undergraduate courses (as described in the courses section) from either the full-time program (540.xxx) or a peer institution.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students may count 400-level courses towards their degree if the course is not offered at the 600-level and if the department offering the course considers it to be graduate-level. Courses offered at both the 400- and 600-levels must be taken at the higher level. No more than three courses can be selected from the Zanvyl Krieger School of Arts and Sciences' Advanced Academic Program in Biotechnology. If a course is not offered in a given term, students may seek advice from the program chair regarding appropriate substitutions. Focus Areas are not required for this program. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

# COURSES

## PREREQUISITE COURSES

545.203 Engineering Thermodynamics
545.204 Applied Physical Chemistry
545.301 Kinetic Processes
545.303 Transport Phenomena I
545.304 Transport Phenomena II
550.291 Linear Algebra & Differential Equations*

*These courses do not count towards degree or certificate requirements.*

*Undergraduate courses from other engineering or science disciplines may be substituted if there is significant overlap in material. Permission to substitute or waive course requirements will be at the discretion of the program chair.*

## RECOMMENDED CORE COURSES

545.602 Metabolic Systems Biotechnology
545.615 Interfacial Science with Applications to Nanoscale Systems
545.643 Chemical Reaction Engineering

## FOCUS AREAS

Students should work with an advisor to choose an appropriate selection of courses in keeping with their desired focus area (Biotechnology or Nanotechnology) and career goals. Focus areas do not appear as official designations on a student's transcript or diploma.

## ADDITIONAL REPRESENTATIVE COURSES

Additional relevant courses are available from Chemical and Biomolecular Engineering and other related majors. The following are presented as aid to students in planning their class schedules. The students are encouraged to seek out other courses of relevance to the Master's degree.

## ELECTIVES

410.601 Advanced Biochemistry†
410.602 Molecular Biology†
410.603 Advanced Cell Biology I†
410.645 Biostatistics†
520.772 Advanced Integrated Circuits‡
540.632 Project in Design: Pharmacokinetics§
545.603 Colloids and Nanoparticles
545.614 Computational Protein Structure Prediction
545.615 Interfacial Science with Applications to Nanoscale Systems
545.619 Project in Design: Alternative Energy
545.621 Project in Design: Pharmacodynamics
545.622 Introduction to Polymeric Materials
545.628 Supramolecular Materials and Nanomedicine
545.630 Thermodynamics and Statistical Mechanics
545.637 Molecular Evolution of Biotechnology
545.640 Micro- and Nanotechnology
545.652 Advanced Transport Phenomena
545.661 Nanobioengineering Laboratory
545.662 Design Projects in Nanobioengineering
545.672 Green Engineering, Alternative Energy, CO2 capture/Sequestration

**550.xxx courses are offered through the full-time the Applied Mathematical and Statistics Department*

*† 410.xxx courses are offered through the part-time Advanced Academic Programs.*

*‡ 520.xxx courses are offered through the full-time Department of Electrical & Computer Engineering.*

580.632 Ionic Channels in Excitable Membranes§
585.605 Medical Imaging
585.606 Medical Image Processing
585.608 Biomaterials
585.609 Cell Mechanics
585.610 Biochemical Sensors
585.618 Biological Fluid and Solid Mechanics

*Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.*

*§580.xxx courses are offered through the full-time Biomedical and Engineering Department.*

# CIVIL ENGINEERING

- **Master's of Civil Engineering**
  *Focus Areas*: Geotechnical Engineering; Structural Engineering
- **Graduate Certificate in Civil Engineering**

The part-time Civil Engineering Program provides graduate instruction in the fields of geotechnical and structural engineering. In addition, the program offers several courses in coastal engineering, a topic relevant to our geographic location. Students in the program may choose to focus their studies in either geotechnical or structural engineering; pursuit of a general civil engineering program is also an option.

Courses are offered at the Dorsey Center and at the Home-wood Campus. Several courses are now also available online.

## PROGRAM COMMITTEE

**RACHEL H. SANGREE, PROGRAM CHAIR**
Lecturer, Civil Engineering, JHU Whiting School of Engineering

**LUCAS DE MELO**
Senior Engineer, Geosyntec Consultants

Adjunct Professor, Civil Engineering, JHU Whiting School of Engineering

**JOHN MATTEO**
Partner, 1200 Architectural Engineers, PLLC

Lecturer, Civil Engineering, JHU Whiting School of Engineering

**BENJAMIN W. SCHAFER**
Department Chair, Civil Engineering, JHU Whiting School of Engineering

# REQUIREMENTS

## MASTER'S

### ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study as outlined in the Admission Requirements section on page 5. The applicant's prior education must include a degree in civil engineering or a closely related technical discipline. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years, with at least five of the courses at the 600-level or above. Students may follow one of two focus areas—geotechnical engineering or structural engineering—or they may choose to design their own course of study in the general field of civil engineering. Focus areas do not appear on a student's transcript, but are important for advising and course planning.

Each focus area consists of three core courses (one course in advanced mathematics and two courses fundamental to the focus area), four additional courses must be chosen from the list of focus area electives, and the remaining three electives may be selected from any of the civil engineering (e.g. 565.XXX) offerings. A maximum of one course may be selected from outside of civil engineering (this does not include the courses outside of civil engineering listed as focus area electives).

The three core courses for any student who does not select a focus area include 535.441 Mathematical Methods for Engineers; 565.475 Advanced Soil Mechanics; and 565.600 Structural Mechanics. Seven additional courses may be chosen from any of the civil engineering offerings. A maximum of one course may be selected from outside of civil engineering.

Any deviations from these requirements must be approved by the Program Chair.

## GRADUATE CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate level courses, but are not necessarily interested in pursuing a full master's degree, are eligible for the Graduate Certificate in Civil Engineering. Admission requirements for the Graduate Certificate in Civil Engineering are the same as those for the Master of Civil Engineering.

Once matriculated, if a student should later decide to pursue the full master's degree, all successfully completed courses will apply provided they meet program requirements and that the remaining courses to be completed fall within a five-year time limit. The student must declare his or her intention prior to completing the certificate.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Each student will work with the program chair to design a program tailored to meet his or her individual goals. Focus areas are not available for students pursing certificates. All course selections are subject to advisor approval.

# COURSES

## MATHEMATICS COURSES

*SELECT ONE*

535.441 Mathematical Methods for Engineers

615.441 Mathematical Methods for Physics and Engineering

## COURSES BY FOCUS AREA

The focus areas offered represent related groups of courses that are relevant for students with interests in the selected areas. The focus areas are presented as an aid to students in planning their course schedules and are only applicable to students seeking a Master's degree.

Focus areas are not required for this program. They do not appear as official designations on a student's transcript or diploma. Students who do not identify with geotechnical engineering or structural engineering may work with their advisor to select a broad yet cohesive group of courses to make up a general program of study in Civil Engineering.

### GEOTECHNICAL ENGINEERING

*CORE COURSES*

565.475 Advanced Soil Mechanics

565.480 Earth Engineering

*ELECTIVES (SELECT AT LEAST FOUR)*

575.426 Hydrogeology

575.429 Modeling Contaminant Migration through Multimedia Systems

565.625 Advanced Foundation Design

565.635 Ground Improvement Methods

565.640 Instrumentation in Structural and Geotechnical Engineering

565.645 Marine Geotechnical Engineering

575.703 Environmental Biotechnology

565.742 Soil Dynamics and Geotechnical Earthquake Engineering

565.745 Retaining Structures and Slope Stability

## STRUCTURAL ENGINEERING

*CORE COURSES*

565.415 Applied Finite Element Methods
565.600 Structural Mechanics

*ELECTIVES (SELECT AT LEAST FOUR)*

565.429 Preservation Engineering: Theory and Practice
565.430 Design of Wood Structures
565.605 Advanced Reinforced Concrete Design
565.620 Advanced Steel Design
565.629 Preservation Engineering in the Urban Context
565.630 Prestressed Concrete Design
565.640 Instrumentation in Structural and Geotechnical Engineering
565.660 Design of Ocean Structures
565.752 Structural Dynamics
565.756 Earthquake Engineering I
565.758 Wind Engineering
565.784 Bridge Design and Evaluation

*For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.*

*Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.*

# COMPUTER SCIENCE

- **Master of Science in Computer Science**
  *Concentrations*: Telecommunications and Networking
  *Tracks*: Bioinformatics, Cybersecurity, Data Communications and Networking, Data Science and Cloud Computing, Database Systems and Knowledge Management, Enterprise and Web Computing, Human–Computer Interaction and Visualization, Software Engineering, Systems, or Theory*

The part-time Computer Science program balances theory with practice, offers an extensive set of traditional and cutting-edge courses, and provides the necessary flexibility to accommodate working professionals with various backgrounds. The program appeals to those with undergraduate degrees in computer science seeking to broaden or deepen their understanding, as well as scientists and engineers who wish to gain deeper insights into the field. The program also can serve as a springboard for career changers looking to gain a thorough, practical understanding of computer science and its related fields.

Courses are offered at the Applied Physics Laboratory, the Dorsey Center, and online.

## PROGRAM COMMITTEE

THOMAS A. LONGSTAFF, PROGRAM CHAIR
Principal Professional Staff, JHU Applied Physics Laboratory

ROBERT S. GROSSMAN, VICE PROGRAM CHAIR EMERITUS
Principal Professional Staff (retired), JHU Applied, Physics Laboratory

JOHN A. PIORKOWSKI, PROGRAM VICE CHAIR
Principal Professional Staff, JHU Applied Physics Laboratory

ELEANOR BOYLE CHLAN, PROGRAM MANAGER
Senior Professional Staff, JHU Applied Physics Laboratory

JACKIE AKINPELU
Principal Professional Staff, JHU Applied Physics Laboratory

MATT BISHOP
Professor, Department of Computer Science, University of California, Davis

ANTON DABHURA
Executive Director, Johns Hopkins University Information Security Institute

DEBORAH DUNIE
Board Director, SAIC

DEBORAH FRINCKE
Director of Research, National Security Agency

GREG HAGER
Computer Science Department Head, JHU Whiting School of Engineering

J. MILLER WHISNANT
Principal Professional Staff, JHU Applied Physics Laboratory

**A track or concentration must be chosen for this program.*

# REQUIREMENTS

## MASTER OF SCIENCE

### ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to a graduate program, as stated in the Admission Requirements section on page 5. The applicant's prior education must include (1) one year of calculus; (2) a mathematics course beyond calculus (e.g., discrete mathematics, linear algebra, or differential equations); (3) a course in data structures; (4) a course in computer organization; and (5) a course in programming using a modern programming language such as Java or C++. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

Prerequisite courses are offered to satisfy computer science and mathematics beyond calculus requirements.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students are required to choose a concentration or track to follow. The curriculum consists of three foundation courses and five courses from the Computer Science (605.xxx) program, or from a list of selected courses from the Cybersecurity (695.xxx) and Information Systems Engineering (635.xxx) programs. At least three courses must be from the same track, and at least two must be at the 700-level or higher. Up to two electives may be selected from the Applied and Computational Mathematics (625.xxx), Applied Physics (615.xxx), and Electrical and Computer Engineering (525.xxx) programs. Electives from other programs require approval of the Computer Science program chair or vice chair. Transfer courses will be considered electives. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

Graduate students who are not pursuing a master's degree in Computer Science should consult with their advisor to determine which courses must be successfully completed before 400- or 700-level Computer Science courses may be taken.

#### *CONCENTRATION*
#### *TELECOMMUNICATIONS AND NETWORKING*

Ten courses must be completed within five years. The curriculum consists of three foundation courses from the program and seven concentration elective courses, a maximum of three of those may come from the Electrical and Computer Engineering (525.xxx) program. Students are strongly encouraged to take courses from both Computer Science and Electrical and Computer Engineering. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

Students lacking an electrical engineering background or equivalent must take 525.202 Signals and Systems as an undergraduate prerequisite before taking Electrical and Computer Engineering telecommunications and networking courses.

Concentrations are noted on the student's transcript.

## POST-MASTER'S CERTIFICATE IN COMPUTER SCIENCE

### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in Computer Science or a closely related technical discipline, such as Electrical and Computer Engineering or Applied and Computational Mathematics, are eligible to apply for the Post Master's Certificate in Computer Science.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Five of the six courses must be Computer Science (605.xxx) courses, and at least two of these courses must be at the 700-level. Only grades of B- or above can count toward the post-master's certificate. Students are allowed to take one elective, subject to advisor approval, with the exception of students focusing on Bioinformatics, who are permitted to apply up to two Bioinformatics courses from the Krieger School of Arts & Sciences Advanced Academic Programs towards the certificate. Tracks are not available for students pursing certificates. All course selections are subject to advisor approval.

## BIOINFORMATICS JOINT PROGRAM

This program is offered jointly by the Zanvyl Krieger School of Arts and Sciences and the Whiting School of Engineering. However, the administration is handled by the Zanvyl Krieger School of Arts and Sciences, and **applications for admission to the Master of Science in Bioinformatics program must be submitted directly to Zanvyl Krieger School of Arts and Sciences** (bioinformatics.jhu.edu). In addition to supplying official transcripts, applicants must provide a résumé or curriculum vitae and a 500-word statement of purpose. The admissions committee reserves the right to request additional information from applicants, such as GRE scores or letters of recommendation, if needed to assess their candidacy for admission.

# COURSES

## PREREQUISITE COURSES

605.101 Introduction to Python
605.201 Introduction to Programming Using Java
605.202 Data Structures
605.203 Discrete Mathematics
605.204 Computer Organization

*These courses do not count towards degree or certificate requirements.*

## FOUNDATION COURSES

Students working toward a master's degree in Computer Science are required to take the following three foundation courses before taking any other courses.

605.401 Foundations of Software Engineering
605.411 Foundations of Computer Architecture
605.421 Foundations of Algorithms

*One or more of the foundation courses can be waived if a student has received an A or B in equivalent courses. In this case, the student may replace the waived foundation courses with the same number of other graduate Computer Science courses and may take these courses after all remaining foundation course requirements have been satisfied.*

## COURSES BY TRACK

The tracks offered represent related groups of courses that are relevant for students with interests in the selected areas. Students are required to choose a track or concentration to follow and to take at least three courses from the selected track. The tracks are presented as an aid to students in planning their course schedules and are only applicable to students seeking a master's degree. They do not appear as official designations on a student's transcript or diploma.

### BIOINFORMATICS

605.451 Principles of Bioinformatics
605.452 Biological Databases and Database Tools
605.453 Computational Genomics
605.456 Computational Drug Discovery and Development
605.457 Statistics for Bioinformatics
605.751 Computational Aspects of Molecular Structure
605.754 Analysis of Gene Expression and High- Content Biological Data
605.755 Systems Biology
605.759 Independent Project in Bioinformatics
605.443 The Semantic Web
605.716 Modeling and Simulation of Complex Systems

### CYBERSECURITY

695.401 Foundations of Information Assurance
695.411 Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms
695.421 Public Key Infrastructure and Managing E-Security
695.422 Web Security
695.442 Intrusion Detection
695.443 Introduction to Ethical Hacking
695.701 Cryptology
695.711 Java Security
695.712 Authentication Technologies in Cybersecurity
695.721 Network Security
695.741 Information Assurance Analysis
695.742 Digital Forensics Technologies and Techniques
695.744 Reverse Engineering and Vulnerability Analysis
695.791 Information Assurance Architectures and Technologies

### DATA COMMUNICATIONS AND NETWORKING

600.647 Advanced Topics in Wireless Networks*
605.471 Principles of Data Communications Networks
605.472 Computer Network Architectures and Protocols
605.473 High-Speed Networking Technologies
605.474 Network Programming
605.475 Protocol Design and Simulation
605.477 Internetworking with TCP/IP I
605.478 Cellular Communications Systems
605.771 Wired and Wireless Local and Metropolitan Area Networks
605.772 Network and Security Management
605.775 Optical Networking Technology
605.776 Fourth-Generation Wireless Communications: WiMAX and LTE
605.777 Internetworking with TCP/IP II
605.778 Voice Over IP
605.779 Network Design and Performance Analysis
525.768 Wireless Networks

### DATA SCIENCE AND CLOUD COMPUTING

605.431 Principles of Cloud Computing
605.432 Graph Analytics
605.433 Social Media Analytics
605.448 Data Science
605.462 Data Visualization
605.725 Queuing theory with Applications to Computer Science

** 600.xxx courses are offered through the full-time Department of Computer Science.*

605.726 Game Theory
605.741 Large-Scale Database Systems
605.744 Information Retrieval
605.746 Machine Learning
605.788 Big Data Processing Using Hadoop

*ADDITIONAL BACKGROUND AND ADVISOR PERMISSION IS REQUIRED*
635.415 Nonlinear Optimization
625.403 Statistical Methods and Data Analysis
625.461 Statistical Models and Regression
625.464 Computational Statistics
625.468 Statistical Privacy Protection in Large Datasets
625.721 Probability and Stochastic Process I
625.722 Probability and Stochastic Process II
625.725 Theory of Statistics I
625.726 Theory of Statistics II
625.740 Data Mining

## DATABASE SYSTEMS AND KNOWLEDGE MANAGEMENT
605.441 Principles of Database Systems
605.443 The Semantic Web
605.444 XML Design Paradigms
605.445 Artificial Intelligence
605.446 Natural Language Processing
605.447 Neural Networks
605.448 Data Science
605.741 Large-Scale Database Systems
605.744 Information Retrieval
605.745 Reasoning Under Uncertainty
605.746 Machine Learning
605.747 Evolutionary Computation
605.748 Semantic Natural Language Processing
605.424 Logic: Systems, Semantics, and Models

## ENTERPRISE AND WEB COMPUTING
605.481 Principles of Enterprise Web Development
605.484 Agile Development with Ruby on Rails
605.486 Mobile Application Development for the Android Platform
605.782 Web Application Development with Java
605.784 Enterprise Computing with Java
605.785 Web Services with SOAP and REST: Frameworks, Processes, and Applications
605.786 Enterprise System Design and Implementation
605.787 Rich Internet Applications with Ajax
605.788 Big Data Processing Using Hadoop
635.483 E-Business: Models, Architecture, Technologies, and Infrastructure

## HUMAN–COMPUTER INTERACTION AND VISUALIZATION
635.461 Principles of Human-Computer Interaction
605.462 Data Visualization
605.467 Computer Graphics
605.767 Applied Computer Graphics

## SOFTWARE ENGINEERING
605.401 Foundations of Software Engineering
605.402 Software Analysis and Design
605.404 Object Oriented Programming with C++
605.405 Conceptual Design for High-Performance Systems
605.407 Agile Software Development Methods
605.408 Software Project Management
605.701 Software Systems Engineering
605.702 Service-Oriented Architecture
605.704 Object-Oriented Analysis and Design
605.705 Software Safety
605.707 Design Patterns
605.708 Tools and Techniques of Software Project Management
605.709 Seminar in Software Engineering
605.429 Programming Languages
695.744 Reverse Engineering and Vulnerability Analysis

## SYSTEMS
605.411 Foundations of Computer Architecture
605.412 Operating Systems
605.414 System Development in the UNIX Environment
605.415 Compiler Design
605.416 Multiprocessor Architecture and Programming
605.417 Introduction to GPU Programming
605.713 Robotics
605.715 Software Development for Real-Time Embedded Systems
605.716 Modeling and Simulation of Complex Systems

## THEORY
605.420 Algorithms for Bioinformatics
605.421 Foundations of Algorithms
605.422 Computational Signal Processing
605.423 Applied Combinatorics and Discrete Mathematics
605.424 Logic: Systems, Semantics, and Models
605.426 Image Processing
605.427 Computational Photography
605.428 Applied Topology

605.429 Programming Languages
605.721 Design and Analysis of Algorithms
605.722 Computational Complexity
605.725 Queuing Theory with Applications to Computer Science
605.726 Game Theory
605.727 Computational Geometry
605.728 Quantum Computation

### INDEPENDENT STUDY

605.801 Independent Study in Computer Science I
605.802 Independent Study in Computer Science II

## COURSES BY CONCENTRATION

### TELECOMMUNICATIONS AND NETWORKING CONCENTRATION

#### *PREREQUISITE*

525.202 Signals and Systems

*This course does not count towards degree or certificate requirements.*

#### *ELECTIVES (SELECT SEVEN–NO MORE THAN THREE COURSES MAY COME FROM ELECTRICAL AND COMPUTER ENGINEERING 525.XXX)*

525.408 Digital Telephony
525.414 Probability and Stochastic Processes for Engineers
525.416 Communication Systems Engineering
525.418 Antenna Systems
525.420 Electromagnetic Transmission Systems
525.438 Introduction to Wireless Technology
525.440 Satellite Communications Systems
525.441 Computer and Data Communication Networks I
525.707 Error Control Coding
525.708 Iterative Methods in Communications Systems
525.722 Wireless and Mobile Cellular Communications
525.723 Computer and Data Communication Networks II
525.735 MIMO Wireless Communications
525.736 Smart Antennas for Wireless Communications
525.738 Advanced Antenna Systems
525.747 Speech Processing
525.751 Software Radio for Wireless Communications
525.754 Wireless Communication Circuits
525.759 Image Compression, Packet Video, and Video Processing
525.761 Wireless and Wireline Network Integration
525.768 Wireless Networks
525.771 Propagation of Radio Waves in the Atmosphere
525.772 Fiber-Optic Communication Systems
525.776 Information Theory
525.783 Spread-Spectrum Communications
525.789 Digital Satellite Communications
525.791 Microwave Communications Laboratory
525.793 Advanced Communication Systems
605.471 Principles of Data Communications Networks
605.472 Computer Network Architectures and Protocols
605.473 High-Speed Networking Technologies
605.474 Network Programming
605.475 Protocol Design and Simulation
605.477 Internetworking with TCP/IP I
605.478 Cellular Communications Systems
605.771 Wired and Wireless Local and Metropolitan Area Networks
605.772 Network and Security Management
605.775 Optical Networking Technology
605.776 Fourth-Generation Wireless Communications: WiMAX and LTE
605.777 Internetworking with TCP/IP II
605.778 Voice Over IP
695.401 Foundations of Information Assurance
695.422 Web Security
695.721 Network Security

***For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.***

***Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.***

# CYBERSECURITY

- **Master of Science in Cybersecurity**
  *Tracks*: Analysis, Networks, or Systems[*]
- **Post-Master's Certificate in Cybersecurity**

The part-time Cybersecurity program balances theory with practice, providing students with the highly technical knowledge and skills needed to protect and defend information systems from attack. Students choose from tracks that explore cyber attacks from within a system, protect information assets, and identify anomalies and unexpected patterns.

Courses are offered at the Applied Physics Laboratory, the Dorsey Center, and online.

## PROGRAM COMMITTEE

**THOMAS A. LONGSTAFF, PROGRAM CHAIR**
Principal Professional Staff, JHU Applied Physics Laboratory

**JOHN A. PIORKOWSKI, PROGRAM VICE CHAIR**
Principal Professional Staff, JHU Applied Physics Laboratory

**ELEANOR BOYLE CHLAN, PROGRAM MANAGER**
Senior Professional Staff, JHU Applied Physics Laboratory

**JACKIE AKINPELU**
Principal Professional Staff, JHU Applied Physics Laboratory

**MATT BISHOP**
Professor, Department of Computer Science, University of California, Davis

**ANTON DABHURA**
Executive Director, Johns Hopkins University Information Security Institute

**DEBORAH DUNIE**
Board Director, SAIC

**DEBORAH FRINCKE**
Director of Research, National Security Agency

**GREG HAGER**
Computer Science Department Head, JHU Whiting School of Engineering

**J. MILLER WHISNANT**
Principal Professional Staff, JHU Applied Physics Laboratory

[*]*A track must be chosen for this program.*

# REQUIREMENTS

## MASTER OF SCIENCE

### ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include (1) one year of calculus; (2) one mathematics course beyond calculus (e.g., discrete mathematics, linear algebra, or differential equations); (3) a programming course using Java or C++; (4) a course in data structures; and (5) a course in computer organization. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

For applicants pursuing one of the three tracks, there area additional requirements. Applicants should have had a course in networking prior to taking courses in the Networks track, a course in operating systems prior to taking courses in the Systems track, and a course in both before taking courses in the Analysis track. If necessary, 605.412 Operating Systems and 605.471 Principles of Data Communications Networks can be taken and applied toward the master's degree in Cybersecurity.

Undergraduate courses are offered to satisfy the to satisfy the computer science and mathematics beyond calculus requirements.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students are required to choose a track to follow. The curriculum consists of three foundation courses and five courses from the Cybersecurity (695.xxx) program, or from a list of selected courses from the Computer Science (605.xxx) program, or Cybersecurity/Security Informatics (650.xxx) and Applied Mathematics and Statistics (550.xxx) Departments in the full-time program. At least three courses must be from the same track. At least two courses must be at the 700-level or higher. Up to two electives may be selected from the Computer Science (605.xxx), Electrical and Computer Engineering (525.xxx), and Applied and Computational Mathematics (625.xxx) programs. Transfer courses will be considered electives. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

Graduate students who are not pursuing a master's degree in Cybersecurity should consult with his/her advisor to determine which courses must be successfully completed before 400- or 700-level courses may be taken. Courses at the 700-level or higher are only open to students who have been admitted with graduate status.

## POST-MASTER'S CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post Master's Certificate in Cybersecurity.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Five of the six courses must be Cybersecurity (695.xxx) courses, and at least two of these courses must be at the 700-level. Students are allowed to take one elective subject to advisor approval. Tracks are not available for students pursing certificates. All course selections are subject to advisor approval.

# COURSES

## FOUNDATION COURSES

The 400-level foundation courses must be taken before other graduate courses, while the 700-level foundation course may be completed anytime after that during the course of the Cybersecurity degree.

605.421 Foundations of Algorithms
695.401 Foundations of Information Assurance
695.701 Cryptology

*One or more foundation courses can be waived by the student's advisor if a student has received an A or B in equivalent courses. In this case, the student may replace the waived foundation courses with the same number of other graduate courses and may take these courses after all remaining foundation course requirements have been satisfied*

## COURSES BY TRACK

The tracks offered represent related groups of courses that are relevant for students with interests in the selected areas. Students are required to choose a track or concentration to follow and to take at least three courses from the selected track.. The tracks are presented as an aid to students in planning their course schedules and are only applicable to students seeking a master's degree. They do not appear as official designations on a student's transcript or diploma.

### ANALYSIS

695.442 Intrusion Detection
695.443 Introduction to Ethical Hacking
695.701 Cryptology
695.741 Information Assurance Analysis
695.742 Digital Forensics Technologies and Techniques
695.744 Reverse Engineering and Vulnerability Analysis
625.468 Statistical Privacy Protection in Large Datasets
650.457 Computer Forensics*

** 650.xxx courses are offered through the Information Security Institute.*

## NETWORKS

695.421 Public Key Infrastructure and Managing E-Security
695.422 Web Security
695.721 Network Security
695.791 Information Assurance Architectures and Technologies
605.471 Principles of Data Communications Networks
605.472 Computer Network Architectures and Protocols
605.474 Network Programming
605.475 Protocol Design and Simulation
605.771 Wired and Wireless Local and Metropolitan Area Networks
600.642 Advanced Topics in Cryptography†

## SYSTEMS

695.401 Foundations of Information Assurance
695.411 Embedded Computer Systems— Vulnerabilities, Intrusions, and Protection Mechanisms
695.711 Java Security
695.712 Authentication Technologies in Cybersecurity
605.401 Foundations of Software Engineering
605.412 Operating Systems
605.421 Foundations of Algorithms
605.704 Object-Oriented Analysis and Design
605.715 Software Development for Real-Time Embedded Systems
605.716 Modeling and Simulation of Complex Systems
600.643 Advanced Topics in Computer Security*
600.648 Secure Software Engineering*
600.650 Advanced Topics in Software Security*
650.471 Cryptography & Coding‡

## INDEPENDENT STUDY

695.801 Independent Study in Cybersecurity I
695.802 Independent Study in Cybersecurity II

***For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.***

***Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.***

*† 600.xxx courses are offered through the full-time Department of Computer Science.*

*‡ 650.xxx courses are offered through the Information Security Institute.*

# ELECTRICAL AND COMPUTER ENGINEERING

- **Master of Science in Electrical and Computer Engineering**
  *Concentrations*: Photonics; Telecommunications and Networking
  *Focus Areas*: Computer Engineering, Electronics and the Solid State, Optics and Photonics, RF and Microwave Engineering, Signal Processing, Systems and Control, Telecommunications and Networking
- **Post-Master's Certificate in Electrical and Computer Engineering**
- **Graduate Certificate in Electrical and Computer Engineering**

The part-time Electrical and Computer Engineering program's strength lies in its faculty, who are drawn from the Applied Physics Laboratory, government and local industry, and from the full-time Department of Electrical & Computer Engineering. Their active involvement in applied research and development helps to foster students' understanding of the theory and practice of the discipline. Students study the fundamentals of electrical and computer engineering, as well as more specific aspects of current technologies based on a variety of technical groupings of courses.

Courses are offered at the Applied Physics Laboratory, the Dorsey Center, and online.

## PROGRAM COMMITTEE

BRIAN K. JENNISON, PROGRAM CHAIR
Principal Professional Staff, JHU Applied Physics Laboratory

CLINTON L. EDWARDS, VICE PROGRAM CHAIR
Senior Professional Staff, JHU Applied Physics Laboratory

JAMES J. COSTABILE
Vice President, Data Design Corporation

JEFFREY G. HOUSER
Electronics Engineer, US Army Research Laboratory

DANIEL G. JABLONSKI
Principal Professional Staff, JHU Applied Physics Laboratory

RALPH ETIENNE-CUMMINGS
Professor, Electrical and Computer Engineering, JHU Whiting School of Engineering

JOHN E. PENN
Electronics Engineer, US Army Research Laboratory

RAYMOND M. SOVA
Principal Professional Staff, JHU Applied Physics Laboratory

DOUGLAS S. WENSTRAND
Principal Professional Staff, JHU Applied Physics Laboratory

# REQUIREMENTS

## MASTER OF SCIENCE

### ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. Applicants are expected to have majored in an Accreditation Board for Engineering and Technology (ABET)-accredited electrical and/or computer engineering program. Those who majored in a related science or engineering field may also be accepted as candidates, provided their background is judged by the admissions committee to be equivalent to that stated above. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

Exceptions to these requirements can be made by the program chair.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years. Seven of the ten courses must be from the Electrical and Computer Engineering program (525.xxx) or the Department of Electrical and Computer Engineering (520.xxx) in the full-time program, and at least four of the ten required courses must be at the 700-level or above.

At most, three of the ten courses required for the MS degree may be selected from outside the program. Students who take an elective outside of the program typically select from approved offerings form the Applied and Computational Mathematics (625.xxx), Applied Physics (615.xxx), and Computer Science (605.xxx) programs.

Limited opportunity is available for replacement of coursework by appropriate project work (525.801 and 525.802) or through a graduate thesis (525.803 and 525.804). Note that 615.441 Mathematical Methods for Physics and Engineering, 615.442 Electromagnetics, 615.780 Optical Detectors and Applications, and 625.743 Stochastic Optimization and Control are counted as Electrical and Computer Engineering courses rather than electives. Only one grade of C may count toward the master's degree. All course selections are subject to advisor approval.

#### *CONCENTRATIONS*

#### *PHOTONICS*

Ten courses must be completed within five years. The curriculum consists of four photonics core courses, three photonics electives, and three additional electives. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

Concentrations are noted on the student's transcript.

#### *TELECOMMUNICATIONS AND NETWORKING*

Ten courses must be completed within five years. The curriculum consists of five Electrical and Computer Engineering telecommunications and networking courses, two Computer Science (605.xxx) telecommunications and networking courses, and three electives. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

Concentrations are noted on the student's transcript.

## POST-MASTER'S CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post Master's Certificate in Electrical and Computer Engineering.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least four of the six courses must be from the Electrical and Computer Engineering (525.xxx) program. Students are allowed to take two electives. Only grades of B- or above can count toward the post-master's certificate. All course selections are subject to advisor approval.

## GRADUATE CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate level courses, but are not necessarily interested in pursuing a full master's degree, are eligible for the Graduate Certificate in Electrical and Computer Engineering. Applicants are required to meet the same requirements for admission as the master's degree.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare his or her intention prior to the completing the certificate.

### CERTIFICATE REQUIREMENTS

Five courses must be completed within three years. At least four of the five courses must be from the Electrical and Computer Engineering (525.xxx) program. Students are allowed to take one elective. Only grades of B- or above can count toward the graduate certificate. All course selections are subject to advisor approval.

# COURSES

## FOCUS AREAS

The focus areas offered represent technology groupings that are relevant for students with interests in the selected areas. Students are not required to choose a focus area to follow. They only serve as an aid to students in planning their course schedules and are only applicable to students seeking a master's degree. They do not appear as official designations on a student's transcript or diploma.

### COMPUTER ENGINEERING

525.410 Microprocessors for Robotic Systems
525.412 Computer Architecture
525.415 Embedded Microprocessor Systems
525.434 High-Speed Digital Design and Signal Integrity
525.441 Computer and Data Communication Networks I
525.442 FPGA Design Using VHDL
525.712 Advanced Computer Architecture
525.723 Computer and Data Communication Networks II
525.742 System-on-a-Chip FPGA Design Laboratory
525.743 Embedded Systems Development Laboratory
525.778 Design for Reliability, Testability, and Quality Assurance
525.786 Human Robotics Interaction

### ELECTRONICS AND THE SOLID STATE

525.406 Electronic Materials
525.407 Introduction to Electronic Packaging
525.421 Introduction to Electronics and the Solid State I
525.422 Introduction to Electronics and the Solid State II
525.424 Analog Electronic Circuit Design I
525.428 Introduction to Digital CMOS VLSI
525.432 Analog Electronic Circuit Design II
525.451 Introduction to Electric Power Systems
525.713 Analog Integrated Circuit Design
525.725 Power Electronics

### OPTICS AND PHOTONICS

525.413 Fourier Techniques in Optics
525.425 Laser Fundamentals
525.436 Optics and Photonics Laboratory
525.491 Fundamentals of Photonics
525.753 Laser Systems and Applications
525.756 Optical Propagation, Sensing, and Backgrounds
525.772 Fiber-Optic Communication Systems
525.792 Electro-Optical Systems
525.796 Introduction to High-Speed Electronics and Optoelectronics
525.797 Advanced Fiber Optic Laboratory

### RF AND MICROWAVE ENGINEERING

525.405 Intermediate Electromagnetics
525.418 Antenna Systems
525.420 Electromagnetic Transmission Systems
525.423 Principles of Microwave Circuits
525.448 Introduction to Radar Systems
525.454 Communications Circuits Laboratory
525.484 Microwave Systems and Components
525.736 Smart Antennas for Wireless Communications
525.738 Advanced Antenna Systems
525.754 Wireless Communication Circuits
525.771 Propagation of Radio Waves in the Atmosphere
525.774 RF and Microwave Circuits I
525.775 RF and Microwave Circuits II
525.779 RF Integrated Circuits
525.787 Microwave Monolithic Integrated Circuit (MMIC) Design
525.788 Power Microwave Monolithic Integrated Circuit (MMIC) Design
525.791 Microwave Communications Laboratory
615.442 Electromagnetics

### SIGNAL PROCESSING

525.419 Introduction to Digital Image and Video Processing
525.427 Digital Signal Processing
525.430 Digital Signal Processing Lab
525.431 Adaptive Signal Processing
525.443 Real-Time Computer Vision
525.446 DSP Hardware Lab
525.448 Introduction to Radar Systems
525.718 Multirate Signal Processing
525.721 Advanced Digital Signal Processing
525.724 Introduction to Pattern Recognition
525.728 Detection and Estimation Theory
525.744 Passive Emitter Geo-Location
525.745 Applied Kalman Filtering
525.746 Image Engineering
525.747 Speech Processing
525.748 Synthetic Aperture Radar
525.762 Signal Processing with Wavelets
525.780 Multidimensional Digital Signal Processing

### SYSTEMS AND CONTROL

525.409 Continuous Control Systems
525.414 Probability and Stochastic Processes for Engineers
525.445 Modern Navigation Systems
525.461 UAV Systems and Control

525.466 Linear System Theory
525.744 Passive Emitter Geo-Location
525.763 Applied Nonlinear Systems
525.770 Intelligent Algorithms
525.777 Control System Design Methods
615.441 Mathematical Methods for Physics and Engineering
625.743 Stochastic Optimization and Control

### TELECOMMUNICATIONS AND NETWORKING

525.408 Digital Telephony
525.414 Probability and Stochastic Processes for Engineers
525.416 Communication Systems Engineering
525.418 Antenna Systems
525.420 Electromagnetic Transmission Systems
525.438 Introduction to Wireless Technology
525.440 Satellite Communications Systems
525.441 Computer and Data Communication Networks I
525.454 Communications Circuits Laboratory
525.707 Error Control Coding
525.708 Iterative Methods in Communications Systems
525.722 Wireless and Mobile Cellular Communications
525.723 Computer and Data Communication Networks II
525.735 MIMO Wireless Communications
525.736 Smart Antennas for Wireless Communications
525.738 Advanced Antenna Systems
525.747 Speech Processing
525.751 Software Radio for Wireless Communications
525.754 Wireless Communication Circuits
525.759 Image Compression, Packet Video, and Video Processing
525.761 Wireless and Wireline Network Integration
525.768 Wireless Networks
525.771 Propagation of Radio Waves in the Atmosphere
525.772 Fiber-Optic Communication Systems
525.776 Information Theory
525.783 Spread-Spectrum Communications
525.789 Digital Satellite Communications
525.791 Microwave Communications Laboratory
525.793 Advanced Communication Systems

## COURSES BY CONCENTRATION

### PHOTONICS

*CORE COURSES (ONLY ONE 615.XXX COURSE IS REQUIRED)*

525.413 Fourier Techniques in Optics
525.425 Laser Fundamentals
525.491 Fundamentals of Photonics
615.441 Mathematical Methods for Physics and Engineering
615.454 Quantum Mechanics
615.471 Principles of Optics

*ELECTIVES FOR THE CONCENTRATION (SELECT THREE)*

525.436 Optics and Photonics Laboratory
525.753 Laser Systems and Applications
525.756 Optical Propagation, Sensing, and Backgrounds
525.772 Fiber-Optic Communication Systems
525.792 Electro-Optical Systems
525.796 Introduction to High-Speed Electronics and Optoelectronics
525.797 Advanced Fiber Optic Laboratory
585.634 Biophotonics
615.751 Modern Optics
615.758 Modern Topics in Applied Optics
615.778 Computer Optical Design
615.780 Optical Detectors and Applications
615.781 Quantum Information Processing
615.782 Optics and MATLAB

*Note: 525.801 and 525.802 Special Project courses can also be used to allow students to pursue specialized interests in optics.*

### TELECOMMUNICATIONS AND NETWORKING

*SELECT FIVE*

525.408 Digital Telephony
525.414 Probability and Stochastic Processes for Engineers
525.416 Communication Systems Engineering
525.418 Antenna Systems
525.420 Electromagnetic Transmission Systems
525.438 Introduction to Wireless Technology
525.440 Satellite Communications Systems
525.441 Computer and Data Communication Networks I
525.454 Communications Circuits Laboratory
525.707 Error Control Coding
525.708 Iterative Methods in Communications Systems
525.722 Wireless and Mobile Cellular Communications
525.723 Computer and Data Communication Networks II
525.735 MIMO Wireless Communications
525.736 Smart Antennas for Wireless Communications
525.738 Advanced Antenna Systems
525.747 Speech Processing
525.751 Software Radio for Wireless Communications
525.754 Wireless Communication Circuits
525.759 Image Compression, Packet Video, and Video Processing
525.761 Wireless and Wireline Network Integration
525.768 Wireless Networks

525.771 Propagation of Radio Waves in the Atmosphere
525.772 Fiber-Optic Communication Systems
525.776 Information Theory
525.783 Spread-Spectrum Communications
525.789 Digital Satellite Communications
525.791 Microwave Communications Laboratory
525.793 Advanced Communication Systems

*SELECT TWO*

605.471 Principles of Data Communications Networks
605.472 Computer Network Architectures and Protocols
605.473 High-Speed Networking Technologies
605.474 Network Programming
605.475 Protocol Design and Simulation
605.477 Internetworking with TCP/IP I
605.478 Cellular Communications Systems
605.771 Wired and Wireless Local and Metropolitan Area Networks
605.772 Network and Security Management
605.775 Optical Networking Technology
605.776 Fourth-Generation Wireless Communications: WiMAX and LTE
605.777 Internetworking with TCP/IP II
605.778 Voice Over IP
695.422 Web Security
695.701 Cryptology
695.721 Network Security

*For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.*

*Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.*

# ENGINEERING MANAGEMENT

- **Master of Engineering Management**
  *Concentrations*: Applied and Computational Mathematics; Applied Biomedical Engineering; Applied Physics; Communications, Controls, and Signal Processing; Computer Engineering; Computer Science; Cybersecurity; Geotechnical Engineering; Information Systems Engineering; Materials Science and Engineering; Mechanical Engineering; Optics and Photonics; RF and Microwave Engineering; or Structural Engineering*

The part-time Engineering Management program provides management course work at the high level expected of managers and technical professionals at engineering firms and R&D organizations. Fourteen concentrations in specific engineering disciplines provide students with a unique opportunity to contribute to a multidisciplinary engineering management team. Emphasis is given to the development of technical, administrative, business, and interpersonal skills required for success in management and leadership positions of continuously changing high-technology organizations and projects.

Courses are offered at the Applied Physics Laboratory, Dorsey Center, in a virtual-live format, and online.

## PROGRAM COMMITTEE

JOSEPH J. SUTER, PROGRAM CHAIR
Principal Professional Staff, JHU Applied Physics Laboratory

JAMES T. (TED) MUELLER, VICE CHAIR
Principal Professional Staff (retired), JHU Applied Physics Laboratory

SHARON B. ALAVI-HANTMAN
Principal Attorney, Avail Law, LLC

ALLAN W. BJERKAAS
Lecturer, JHU Whiting School of Engineering

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LORENZ J. (JIM) HAPPEL
Principal Professional Staff, JHU Applied Physics Laboratory

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ALMA MILLER
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JOHN A. PIORKOWSKI
Principal Professional Staff, JHU Applied Physics Laboratory

ANDREA PROSPERETTI
Program Chair, Mechanical Engineering, Johns Hopkins Engineering for Professionals

STANISLAW E. TARCHALSKI
Director (retired), IBM Corporation

JUDITH G. THEODORI
Principal Professional Staff, JHU Applied Physics Laboratory

**A concentration must be chosen for this program.*

# REQUIREMENTS

## MASTER'S

### ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to a graduate program outlined in the Admission Requirements section on page 5. The applicant's prior education must include a degree in a science or an engineering field. In addition to this requirement, a minimum of two years of relevant full-time work experience in the field and a detailed work résumé must be submitted. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of five core courses and five courses from the concentration. At least three of the courses must be at the 700-level. Only one grade of C can count toward the master's degree. Concentrations are noted on the student's transcript. All course selections are subject to advisor approval.

# COURSES

## CORE COURSES

*SELECT FIVE*

*Course substitutions can be made at the discretion of the program chair.*

595.460 Introduction to Project Management
595.465 Communications in Technical Organizations
595.466 Financial and Contract Management
595.731 Business Law for Technical Professionals
595.762 Management of Technical Organizations
595.781 Executive Technical Leadership
595.792 Management of Innovation

## COURSES BY CONCENTRATION

### APPLIED AND COMPUTATIONAL MATHEMATICS

**Select five** courses from the Applied and Computational Mathematics program [ep.jhu.edu/acm] 625.xxx. Selected courses include

625.403 Statistical Methods and Data Analysis
625.414 Linear Optimization
625.423 Introduction to Operations Research: Probabilistic Models
625.441 Mathematics of Finance: Investment Science
625.442 Mathematics of Risk, Options, and Financial Derivatives
625.740 Data Mining
625.741 Game Theory
625.744 Modeling, Simulation, and Monte Carlo

*One course (with significant math content) outside of Applied and Computational Mathematics may be taken with advisor approval.*

### APPLIED BIOMEDICAL ENGINEERING

*SELECT FIVE*

*Courses not on the list can be approved by the student's advisor.*

585.408 Medical Sensors and Devices
585.605 Medical Imaging
585.608 Biomaterials
585.629 Cell and Tissue Engineering
585.800 Special Project in Applied Biomedical Engineering

### APPLIED PHYSICS

*SELECT FIVE (AT LEAST FOUR MUST BE 615.XXX COURSES)*

*Students must complete five courses approved by their advisor. At least four courses must be from Applied Physics. The following courses are recommended for this concentration, but the advisor can approve courses that do not appear on this list.*

525.406 Electronic Materials
525.407 Introduction to Electronic Packaging
615.444 Fundamentals of Space Systems and Subsystems I
615.445 Fundamentals of Space Systems and Subsystems II
615.447 Fundamentals of Sensors
615.448 Alternate Energy Technology
615.465 Modern Physics
615.471 Principles of Optics
615.480 Materials Science
615.731 Photovoltaic & Solar Thermal Energy Conversion
615.746 Nanoelectronics: Physics and Devices
615.747 Sensors and Sensor Systems
615.761 Introduction to Oceanography
615.765 Chaos and Its Applications
615.775 Physics of Climate
615.780 Optical Detectors and Applications

### COMMUNICATIONS, CONTROLS, AND SIGNAL PROCESSING

*CORE COURSES*

525.409 Continuous Control Systems
525.414 Probability and Stochastic Processes for Engineers
525.416 Communication Systems Engineering
525.427 Digital Signal Processing

***Plus one*** *additional Electrical and Computer Engineering (525.xxx) course with advisor approval. One course outside of the program may be taken provided it has significant technical content.*

## COMPUTER ENGINEERING

*CORE COURSES*

525.412 Computer Architecture

525.415 Embedded Microprocessor Systems

525.442 FPGA Design Using VHDL

525.743 Embedded Systems Development Laboratory

***Plus one*** *additional Electrical and Computer Engineering (525.xxx) course with advisor approval. One course outside of the program may be taken provided it has significant technical content.*

## COMPUTER SCIENCE

*CORE COURSES*

605.401 Foundations of Software Engineering

605.411 Foundations of Computer Architecture

605.421 Foundations of Algorithms

*SELECT ONE*

605.431 Principles of Cloud Computing

605.441 Principles of Database Systems

605.445 Artificial Intelligence

605.451 Principles of Bioinformatics

605.471 Principles of Data Communications Networks

605.481 Principles of Enterprise Web Development

695.401 Foundations of Information Assurance

***Plus one*** *additional Computer Science course with advisor approval.*

## CYBERSECURITY

*CORE COURSES*

605.421 Foundations of Algorithms

695.401 Foundations of Information Assurance

695.421 Public Key Infrastructure and Managing E-Security

695.701 Cryptology

***Plus one*** *additional Cybersecurity course with advisor approval.*

## GEOTECHNICAL ENGINEERING

**Select four** courses in Geotechnical Engineering [ep.jhu.edu/ce] 565.xxx, plus one course in mathematics. Selected Geotechnical Engineering courses include

565.475 Advanced Soil Mechanics

565.480 Earth Engineering

565.625 Advanced Foundation Design

565.745 Retaining Structures and Slope Stability

*RECOMMENDED MATHEMATICS COURSES*

535.441 Mathematical Methods for Engineers

615.441 Mathematical Methods for Physics and Engineering

## INFORMATION SYSTEMS ENGINEERING

*CORE COURSES*

605.401 Foundations of Software Engineering

635.401 Foundations of Information Systems Engineering

695.401 Foundations of Information Assurance

*SELECT ONE*

635.411 Principles of Network Engineering

635.461 Principles of Human-Computer Interaction

635.476 Information Systems Security

635.482 Website Development

635.483 E-Business: Models, Architecture, Technologies, and Infrastructure

635.775 Cyber Policy, Law, and Cyber Crime Investigation

**Plus one** *additional Information Systems Engineering course with advisor approval.*

## MATERIALS SCIENCE AND ENGINEERING

**Select five** courses from the Materials Science and Engineering program [ep.jhu.edu/mse] 515.xxx. The advisor from the concentration will have the flexibility to work with each student to determine the appropriate mix of technical courses.

## MECHANICAL ENGINEERING

**Select five** courses from the Mechanical Engineering program [ep.jhu.edu/me] 535.xxx. The advisor from the concentration will have the flexibility to work with each student to determine the appropriate mix of technical courses.

## OPTICS AND PHOTONICS

*CORE COURSES*

525.405 Intermediate Electromagnetics

525.413 Fourier Techniques in Optics

525.425 Laser Fundamentals

525.491 Fundamentals of Photonics

***Plus one*** *additional Electrical and Computer Engineering (525.xxx) course with advisor approval. One course outside of the program may be taken provided it has significant technical content.*

## RF AND MICROWAVE ENGINEERING

*CORE COURSES*

525.405 Intermediate Electromagnetics

525.418 Antenna Systems

525.423 Principles of Microwave Circuits

525.484 Microwave Systems and Components

***Plus one*** *additional Electrical and Computer Engineering (525.xxx) course with advisor approval. Courses outside of the program may be taken provided they have significant technical content.*

## STRUCTURAL ENGINEERING

**Select four** courses in Structural Engineering [ep.jhu.edu/ce] 565.xxx, plus one course in mathematics. Selected Structural Engineering courses include

565.600 Structural Mechanics

565.620 Advanced Steel Design

565.630 Prestressed Concrete Design

565.784 Bridge Design and Evaluation

### *RECOMMENDED MATHEMATICS COURSES*

535.441 Mathematical Methods for Engineers

615.441 Mathematical Methods for Physics and Engineering

*For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.*

*Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.*

# ENVIRONMENTAL ENGINEERING, SCIENCE, AND MANAGEMENT PROGRAMS

The part-time programs in Climate Change, Energy, and Environmental Sustainability; Environmental Engineering; Environmental Engineering and Science; and Environmental Planning and Management address an array of modern environmental issues while capitalizing on environmental protection and remediation solutions made possible by technology. Students improve their understanding in these areas through a quantitative program built around the common theme of engineering and science in support of environmental decision making and management. The strength of the programs lies in a faculty of working professionals and from the nationally renowned full-time Department of Geography & Environmental Engineering.

All four of these programs are only offered online.

## PROGRAM COMMITTEE

**HEDY V. ALAVI, PROGRAM CHAIR**
Assistant Dean, International Programs, JHU Whiting School of Engineering

Environmental Engineering, Science, and Management programs, Johns Hopkins Engineering for Professionals

**WHITING SCHOOL'S DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL ENGINEERING**
*The entire faculty of the Whiting School's Department of Geography and Environmental Engineering functions as the program committee for the four environmental programs. This committee ensures that instruction in the part-time program is of the highest quality and is continually enhanced in a manner consistent with parallel developments in the full-time program.*

## FACULTY

The program features highly qualified instructors who are distinguished and experienced professionals. Each holds the highest academic degree in his or her field of expertise, and has demonstrated a strong commitment to excellence in teaching.

Many of the outstanding full-time faculty from the renowned full-time Department of Geography and Environmental Engineering serve as instructors. The program also includes directors, senior scientists, engineers, researchers, and attorneys affiliated with the Maryland Department of the Environment, Nuclear Regulatory Agency, US Department of Energy, US Department of Defense, US Environmental Protection Agency, and many leading environmental consulting companies.

Please see the Faculty section on page 183 for the list of active faculty members and their affiliations.

# CLIMATE CHANGE, ENERGY, AND ENVIRONMENTAL SUSTAINABILITY

- Post-Master's Certificate in Climate Change, Energy, and Environmental Sustainability *(online only)*

## REQUIREMENTS

### POST-MASTER'S CERTIFICATE

#### ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include a master's degree in Environmental Engineering, Science, Management, or a similar technical discipline.

#### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. The curriculum consists of five core courses and one elective. At least a total of four courses must be completed at the 700-level or above. Electives may be substituted for a required course if the student has previously completed an equivalent graduate-level course, or can demonstrate competency. Only grades of B- or above can count toward the post-master's certificate. All course selections are subject to advisor approval.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

## COURSES

### CORE COURSES

575.711 Climate Change and Global Environmental Sustainability
575.720 Air Resources Modeling and Management
575.723 Sustainable Development and Next-Generation Buildings
575.733 Energy Planning and the Environment
575.734 Smart Growth Strategies for Sustainable Urban Development and Revitalization

### ELECTIVES

*SELECT ONE*

575.408 Optimization Methods for Public Decision Making
575.411 Economic Foundations for Public Decision Making
575.423 Industrial Processes and Pollution Prevention
575.435 Environmental Law for Engineers and Scientists
575.437 Environmental Impact Assessment
575.710 Financing Environmental Projects
575.721 Air Quality Control Technologies
575.743 Atmospheric Chemistry
575.759 Environmental Policy Analysis
575.801 Independent Project in Environmental Engineering, Science, and Management

*For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.*

*Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.*

# ENVIRONMENTAL ENGINEERING

- **Master of Environmental Engineering** *(online only)*
- **Master of Environmental Engineering/Master of Business Administration** *(dual degree with The Johns Hopkins University Carey Business School)*
- **Post-Master's Certificate in Environmental Engineering** *(online only)*
- **Graduate Certificate in Environmental Engineering** *(online only)*

## REQUIREMENTS

### MASTER'S

#### ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include (1) an undergraduate degree or demonstrated equivalent in an engineering discipline from an ABET-accredited four-year regionally accredited college or university; (2) Successful completion of calculus sequence through differential equations; and (3) Successful completion of a course in fluid mechanics or hydraulics is strongly recommended. Successful completion of a course in statistics is also recommended. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

Applicants with an undergraduate degree in natural sciences may be admitted as provisional students to complete additional undergraduate coursework in engineering fundamentals and design prior to full admission to the program.

#### DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of five courses from the Environmental Engineering program and five electives. Electives may be selected from any of the three environmental areas of study: Environmental Engineering, Environmental Engineering and Science, or Environmental Planning and Management, subject to prerequisite restrictions. At least four courses at the 700-level. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

The Principles of Environmental Engineering (575.404) course is required of all degree students in the Environmental Engineering program who do not possess an undergraduate degree in Environmental Engineering, Science, Management, or a related discipline.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

### POST-MASTER'S CERTIFICATE

#### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post Master's Certificate in Environmental Engineering.

#### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least three of the six courses must be taken within the Environmental Engineering program and at least three at the 700-level or higher. Only grades of B- or above can count towards the post-master's certificate. All course selections are subject to advisor approval.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

### GRADUATE CERTIFICATE

#### ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate level courses, but are not necessarily interested in pursuing a full master's degree, are eligible for the Graduate Certificate in Environmental Engineering. Applicants are required to meet the same requirements for admission as the master's degree.

Applicants must have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Significant relevant work experience or a graduate degree in a relevant technical discipline may be considered in lieu of meeting the GPA requirement.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare his or her intention prior to the completing the certificate.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Only grades of B- or above can count towards the graduate certificate. All course selections are subject to advisor approval.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

## DUAL-DEGREE

### ADMISSION REQUIREMENTS

Johns Hopkins Engineering for Professionals and the Carey Business School offer a dual-degree program in which students are admitted to the Master of Environmental Engineering within Johns Hopkins Engineering for Professionals and the Flexible MBA program within the Carey Business School, either simultaneously or sequentially, and receive two separate degrees, one from each school, in a shorter period of time.

Applicants applying to the dual-degree program must satisfy the admission requirements of both the Environmental Engineering program and the Master of Business Administration program. Each school decides on admission separately. Applicants applying for the dual-degree should complete the Engineering for Professionals application, and submit supporting document and application fee to Engineering for Professionals.

For additional information about the Flexible MBA program at the Carey Business School, please visit the Carey website at carey.jhu.edu.

### DUAL-DEGREE REQUIREMENTS

Students must successfully complete the requirements for both programs in order to be awarded the two degrees. For the Johns Hopkins Engineering for Professionals degree, students will be able to count two Johns Hopkins Engineering for Professionals course equivalents of academic credit from their Carey MBA toward their ten-course Johns Hopkins Engineering for Professionals degree requirements. Students in this program will complete the Master of Environmental Engineering online. All course selections are subject to advisor approval.

For the Engineering for Professionals degree, students will be able to count two Engineering for Professionals course equivalents of academic credit from their Carey MBA toward their 10-course Engineering for Professionals degree requirements. For the MBA degree, students will be able to count the academic equivalent of 12 credits from their Engineering for Professionals program toward the Carey 54-credit Professional MBA program. By the end of the dual-degree program, students will have completed 66 credits (28 courses) rather than 84 credits (36 courses) that would otherwise be required when pursuing these two programs independently.

## COURSES

### FOR ENVIRONMENTAL ENGINEERING

*SELECT FIVE*

575.404 Principles of Environmental Engineering*
575.405 Principles of Water and Wastewater Treatment
575.406 Water Supply and Wastewater Collection
575.407 Radioactive Waste Management
575.420 Solid Waste Engineering and Management
575.423 Industrial Processes and Pollution Prevention
575.703 Environmental Biotechnology
575.706 Biological Processes for Water and Wastewater Treatment
575.715 Subsurface Fate and Contaminant Transport
575.721 Air Quality Control Technologies
575.722 Sensor Application for Environmental Exposure Monitoring
575.742 Hazardous Waste Engineering and Management
575.745 Physical and Chemical Processes for Water and Wastewater Treatment
575.746 Water and Wastewater Treatment Plant Design
575.801 Independent Project in Environmental Engineering, Science, and Management

*Plus five courses from the list above, or pages 60 and 63.*

* *Required only for students who do not possess an undergraduate degree in environmental engineering, science, and management or a related discipline.*

***For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.***

***Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors***

# ENVIRONMENTAL ENGINEERING AND SCIENCE

- **Master of Science in Environmental Engineering and Science** *(online only)*
- **Master of Science in Environmental Engineering and Science/Master of Business Administration** *(dual degree with The Johns Hopkins University Carey Business School)*
- **Post-Master's Certificate in Environmental Engineering and Science** *(online only)*
- **Graduate Certificate in Environmental Engineering and Science** *(online only)*

## REQUIREMENTS

### MASTER OF SCIENCE

#### ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include (1) an undergraduate degree from a regionally accredited four-year college or university; (2) Successful completion of a calculus sequence through differential equations; and (3) Successful completion of physics, chemistry, biology, geology, and statistics is recommended. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

#### DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of five courses from the Environmental Engineering and Science program and five electives. Electives may be selected from any of the three environmental areas of study: Environmental Engineering, Environmental Engineering and Science, or Environmental Planning and Management, subject to prerequisite restrictions. At least a total of four courses must be completed at the 700-level or above. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

The Principles of Environmental Engineering (575.404) course is required of all degree students in the Environmental Engineering program who do not possess an undergraduate degree in Environmental Engineering, Science, Management, or a related discipline.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

### POST-MASTER'S CERTIFICATE

#### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post Master's Certificate in Environmental Engineering and Science.

#### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least three of the six courses must be taken within the Environmental Engineering and Science program and at least three must be at the 700-level or higher. Only grades of B- or above can count towards the post-master's certificate. All course selections are subject to advisor approval.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

### GRADUATE CERTIFICATE

#### ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate level courses, but are not necessarily interested in pursuing a full master's degree, are eligible for the Graduate Certificate in Environmental Engineering and Science. Applicants are required to meet the same requirements for admission as the master's degree.

Applicants must have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Significant relevant work experience or a graduate degree in a relevant technical discipline may be considered in lieu of meeting the GPA requirement.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare his or her intention prior to the completing the certificate.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Only grades of B- or above can count towards the graduate certificate. All course selections are subject to advisor approval.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

## DUAL-DEGREE

### ADMISSION REQUIREMENTS

Johns Hopkins Engineering for Professionals and the Carey Business School offer a dual-degree program in which students are admitted to the Master of Environmental Engineering and Science within Johns Hopkins Engineering for Professionals and the Flexible MBA program within the Carey Business School, either simultaneously or sequentially, and receive two separate degrees, one from each school, in a shorter period of time.

Applicants applying to the dual-degree program must satisfy the admission requirements of both the Environmental Engineering and Science program and the Master of Business Administration program. Each school decides on admission separately. Applicants applying for the dual-degree should complete the Engineering for Professionals application, and submit supporting document and application fee to Engineering for Professionals.

For additional information about the Flexible MBA program at the Carey Business School, please visit the Carey website at carey.jhu.edu.

### DUAL-DEGREE REQUIREMENTS

Students must successfully complete the requirements for both programs in order to be awarded the two degrees. For the Johns Hopkins Engineering for Professionals degree, students will be able to count two Johns Hopkins Engineering for Professionals course equivalents of academic credit from their Carey MBA toward their ten-course Johns Hopkins Engineering for Professionals degree requirements. Students in this program will complete the Master of Science in Environmental Engineering and Science online.

For the Engineering for Professionals degree, students will be able to count two Engineering for Professionals course equivalents of academic credit from their Carey MBA toward their 10-course Engineering for Professionals degree requirements. For the MBA degree, students will be able to count the academic equivalent of 12 credits from their Engineering for Professionals program toward the Carey 54-credit Professional MBA program.

By the end of the dual-degree program, students will have completed 66 credits (28 courses) rather than 84 credits (36 courses) that would otherwise be required when pursuing these two programs independently.

## COURSES

### REQUIRED COURSE

575.404 Principles of Environmental Engineering*

** Required only for students who do not possess an undergraduate degree in environmental engineering, science, and management or a related discipline.*

### COURSES FOR ENVIRONMENTAL ENGINEERING AND SCIENCE

*SELECT FIVE*

575.401 Fluid Mechanics
575.415 Ecology
575.419 Principles of Toxicology, Risk Assessment, and Management
575.426 Hydrogeology
575.429 Modeling Contaminant Migration through Multimedia Systems
575.443 Aquatic Chemistry
575.445 Environmental Microbiology
575.704 Applied Statistical Analyses and Design of Experiments for Environmental Applications
575.708 Open Channel Hydraulics
575.713 Field Methods in Habitat Analysis and Wetland Delineation
575.716 Principles of Estuarine Environment: The Chesapeake Bay Science and Management
575.717 Hydrology
575.720 Air Resources Modeling and Management
575.727 Environmental Monitoring and Sampling
575.743 Atmospheric Chemistry
575.744 Environmental Chemistry
575.763 Nanotechnology and the Environment: Applications and Implications
575.801 Independent Project in Environmental Engineering, Science, and Management

*Plus five courses from the list above, or pages 58 and 63. Or four courses plus 575.404 if required.*

***For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.***

***Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.***

# ENVIRONMENTAL PLANNING AND MANAGEMENT

- **Master of Science in Environmental Planning and Management** *(online only)*
- **Master of Science in Environmental Planning and Management/Master of Business Administration** *(dual degree with The Johns Hopkins University Carey Business School)*
- **Post-Master's Certificate in Environmental Planning and Management** *(online only)*
- **Graduate Certificate in Environmental Planning and Management** *(online only)*
- **Graduate Certificate in Environmental Planning and Management/Master of Science in Applied Economics** *(dual program with Johns Hopkins Advanced Academic Programs)*

## REQUIREMENTS

### MASTER OF SCIENCE

#### ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include (1) an undergraduate degree in engineering, natural science, economics, planning, management, or other related discipline from a four-year regionally accredited college or university; (2) Successful completion of one year of college-level calculus and (3) Successful completion of college-level courses is recommended in physics, chemistry, biology, geology, and statistics. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

#### DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of five courses from the Environmental Planning and Management program and five electives. Electives may be selected from any of the three environmental areas of study: Environmental Engineering, Environmental Engineering and Science, or Environmental Planning and Management, subject to prerequisite restrictions. At least a total of four courses must be completed at the 700-level or above. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

The Principles of Environmental Engineering (575.404) course is required of all degree students in the Environmental Engineering program who do not possess an undergraduate degree in Environmental Engineering, Science, Management, or a related discipline.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

### POST-MASTER'S CERTIFICATE

#### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post Master's Certificate in Environmental Planning and Management.

#### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least three of the six courses must be taken within the Environmental Planning and Management program, at least three must be at the 700-level or higher. Only grades of B- or above can count towards the post-master's certificate.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

### GRADUATE CERTIFICATE

#### ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate level courses, but are not necessarily interested in pursuing a full master's degree, are eligible for the Graduate Certificate in Environmental Planning and Management. Applicants are required to meet the same requirements for admission as the master's degree.

Applicants must have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Significant relevant work experience or a graduate degree in a relevant technical discipline may be considered in lieu of meeting the GPA requirement.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare his or her intention prior to the completing the certificate.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Only grades of B- or above can count towards the graduate certificate. All course selections are subject to advisor approval.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

## DUAL-DEGREE

### ADMISSION REQUIREMENTS

Johns Hopkins Engineering for Professionals and the Carey Business School offer a dual-degree program in which students are admitted to the Master of Environmental Planning and Management within Johns Hopkins Engineering for Professionals and the Flexible MBA program within the Carey Business School, either simultaneously or sequentially, and receive two separate degrees, one from each school, in a shorter period of time.

Applicants applying to the dual-degree program must satisfy the admission requirements of both the Environmental Planning and Management program and the Master of Business Administration program. Each school decides on admission separately. Applicants applying for the dual-degree should complete the Engineering for Professionals application, and submit supporting document and application fee to Engineering for Professionals.

For additional information about the Flexible MBA program at the Carey Business School, please visit the Carey website at carey.jhu.edu.

### DEGREE REQUIREMENTS

Students must successfully complete the requirements for both programs in order to be awarded the two degrees. For the Johns Hopkins Engineering for Professionals degree, students will be able to count two Johns Hopkins Engineering for Professionals course equivalents of academic credit from their Carey MBA toward their ten-course Johns Hopkins Engineering for Professionals degree requirements. Students in this program will complete the Master of Science in Environmental Planning and Management online.

For the Engineering for Professionals degree, students will be able to count two Engineering for Professionals course equivalents of academic credit from their Carey MBA toward their 10-course Engineering for Professionals degree requirements. For the MBA degree, students will be able to count the academic equivalent of 12 credits from their Engineering for Professionals program toward the Carey 54-credit Professional MBA program.

By the end of the dual-degree program, students will have completed 66 credits (28 courses) rather than 84 credits (36 courses) that would otherwise be required when pursuing these two programs independently.

## DUAL DEGREE/CERTIFICATE

### ADMISSION REQUIREMENTS

Johns Hopkins Engineering for Professionals (EP) and Johns Hopkins Advanced Academic Programs (AAP) offer a dual-program in which students are admitting to the Environmental Planning and Management program within EP and the Applied Economics program within AAP. Students earn a Master of Science in Applied Economics and a Graduate Certificate in Environmental Planning and Management. EP courses can only be completed online, AAP courses are offered in Washington, D.C. near Dupont Circle.

Applicants applying to the dual-degree and certificate program must satisfy the admission requirements of both the Environmental Planning and Management program and the Master of Science in Applied Economics program. Each school decides on admission separately. Applicants applying for the dual-degree and certificate program should apply through AAP.

For additional information, or to apply, please visit AAP's website at advanced.jhu.edu.

### CERTIFICATE REQUIREMENTS

Fourteen courses must be completed in three years. The curriculum consists of nine courses from the Applied Economics program (440.xxx) and five courses from the Environmental Planning and Management program (575.xxx). Students must successfully complete the requirements for both degrees in order to be awarded the two degrees. Only grades of B- or above can count towards the post-master's certificate.

Students in this program will complete the Graduate Certificate in Environmental Planning and Management online.

# COURSES

## REQUIRED COURSE

575.404 Principles of Environmental Engineering*

** Required only for students who do not possess an undergraduate degree in environmental engineering, science, and management or a related discipline.*

## COURSES FOR ENVIRONMENTAL PLANNING AND MANAGEMENT

*SELECT FIVE*

575.408 Optimization Methods for Public Decision Making
575.411 Economic Foundations for Public Decision Making
575.416 Engineering Risk and Decision Analysis
575.428 Business Law for Engineers
575.435 Environmental Law for Engineers and Scientists
575.437 Environmental Impact Assessment
575.440 Geographic Information Systems (GIS) and Remote Sensing for Environmental Applications
575.707 Environmental Compliance Management
575.710 Financing Environmental Projects
575.711 Climate Change and Global Environmental Sustainability
575.714 Water Resources Management
575.723 Sustainable Development and Next- Generation Buildings
575.731 Water Resources Planning
575.733 Energy Planning and the Environment
575.734 Smart Growth Strategies for Sustainable Urban Development and Revitalization
575.737 Environmental Security with Applied Decision Analysis Tools
575.747 Environmental Project Management
575.748 Environmental Management Systems
575.750 Environmental Policy Needs in Developing Countries
575.752 Environmental Justice and Ethics Incorporated into Environmental Decision-Making
575.759 Environmental Policy Analysis
575.753 Communication of Environmental Information and Stakeholder Engagement
575.801 Independent Project in Environmental Engineering, Science, and Management

*Plus five courses from the list above, or pages 58 and 60. Or four courses plus 575.404 if required.*

***For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.***

***Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors***

# INFORMATION SYSTEMS ENGINEERING

- **Master of Science in Information Systems Engineering**
  *Tracks*: Cybersecurity, Enterprise and Web Computing, Human–Computer Interaction, Information Management, Network Engineering, Software Engineering, or Systems Engineering*
- **Post-Master's Certificate in Information Systems Engineering**
- **Graduate Certificate in Information Systems Engineering**

The part-time Information Systems Engineering program balances theory with practice by offering traditional and cutting-edge courses that accommodate working professionals with various backgrounds. The program appeals to engineers and scientists by providing them with the opportunity to design large-scale information systems, develop efficient network architectures, conduct complex systems analyses, and create sophisticated distributed and secure systems.

Courses are offered at the Applied Physics Laboratory, the Dorsey Center, and online.

## PROGRAM COMMITTEE

**THOMAS A. LONGSTAFF, PROGRAM CHAIR**
Principal Professional Staff, JHU Applied Physics Laboratory

**JOHN A. PIORKOWSKI, PROGRAM VICE CHAIR**
Principal Professional Staff, JHU Applied Physics Laboratory

**ELEANOR BOYLE CHLAN, PROGRAM MANAGER**
Senior Professional Staff, JHU Applied Physics Laboratory

**JACKIE AKINPELU**
Principal Professional Staff, JHU Applied Physics Laboratory

**ANTON DABHURA**
Executive Director, Johns Hopkins University Information Security Institute

**DEBORAH DUNIE**
Board Director, SAIC

**DEBORAH FRINCKE**
Director of Research, National Security Agency

**GREG HAGER**
Computer Science department Head, JHU Whiting School of Engineering

**J. MILLER WHISNANT**
Principal Professional Staff, JHU Applied Physics Laboratory

**A track must be chosen for this program.*

# REQUIREMENTS

## MASTER OF SCIENCE

### ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include one year of college math including one semester of calculus or discrete mathematics; and a course in programming using a modern programming language such as Java or C++. Data Structures may also be required for students seeking to take selected courses from Computer Science and Cybersecurity. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students are required to choose a track to follow. The curriculum consists of three foundation courses and five courses from the Information Systems Engineering (635.xxx) program, including selected courses from the Computer Science (605.xxx), Cybersecurity (695.xxx), System Engineering (645.xxx), and Technical Management (595.xxx) programs. At least three courses must be from the same track, and at least two courses must be at the 700-level or higher. Up to two electives may be selected from other programs. Courses listed on pages 65–66 are considered electives for Information Systems Engineering, and require approval. Some courses may require approval of the Information Systems Engineering program chair or vice chair. Transfer courses will be considered electives. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

Graduate students who are not pursuing a master's degree in Information Systems Engineering should consult with his/her advisor to determine which courses must be successfully completed before 400- or 700-level courses may be taken. Courses at the 700-level or higher are only open to students who have been admitted with graduate status.

## POST-MASTER'S CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post Master's Certificate in Information Systems Engineering. One elective is allowed.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. The curriculum consists of five foundation courses and one elective. Five of the six courses must be from the Information Systems Engineering program listed throughout the Courses section, and at least two of these courses must be at the 700-level. Tracks are not available for students pursing certificates. All course selections are subject to advisor approval.

## GRADUATE CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate level courses, but are not necessarily interested in pursuing a full master's degree, are eligible for the Graduate Certificate in Information Systems Engineering. Applicants are required to meet the same requirements for admission as the master's degree.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare his or her intention prior to the completing the certificate.

### CERTIFICATE REQUIREMENTS

Five courses must be completed within three years. The curriculum consists of four foundation courses and one elective. Four of the five courses must be from the Information Systems Engineering program listed throughout the Courses section. Tracks are not available for students pursing certificates. All course selections are subject to advisor approval.

# COURSES

## PREREQUISITES

605.201 Introduction to Programming Using Java
605.202 Data Structures
605.203 Discrete Mathematics

*These courses do not count towards degree or certificate requirements.*

## FOUNDATION COURSES

Students working toward a master's degree in Information Systems Engineering are required to take the following three foundation courses before taking any other courses.

605.401 Foundations of Software Engineering
635.401 Foundations of Information Systems Engineering
695.401 Foundations of Information Assurance

*One or more foundation courses can be waived by the student's advisor if a student has received an A or B in equivalent courses. In this case, the student may replace the waived foundation courses with the same number of other graduate* *courses and may take these courses after all remaining foundation course requirements have been satisfied.*

## COURSES BY TRACK

The tracks offered represent related groups of courses that are relevant for students with interests in the selected areas. Students are required to choose a track to follow and to take at least three courses from the selected track. The tracks are presented as an aid to students in planning their course schedules and are only applicable to students seeking a master's degree. They do not appear as official designations on a student's transcript or diploma.

### CYBERSECURITY

635.471 Data Recovery and Continuing Operations
635.476 Information Systems Security
635.775 Cyber Policy, Law, and Cyber Crime Investigation
635.776 Building Information Governance
695.401 Foundations of Information Assurance
695.411 Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms*
695.421 Public Key Infrastructure and Managing E-Security*
695.422 Web Security*
695.442 Intrusion Detection*
695.443 Introduction to Ethical Hacking*
695.711 Java Security*
695.712 Authentication Technologies in Cybersecurity*
695.721 Network Security*
695.744 Reverse Engineering and Vulnerability Analysis
695.791 Information Assurance Architectures and Technologies*

### ENTERPRISE AND WEB COMPUTING

635.482 Website Development
635.483 E-Business: Models, Architecture, Technologies, and Infrastructure
605.481 Principles of Enterprise Web Development*
605.484 Agile Development with Ruby on Rails*
605.486 Mobile Application Development for the Android Platform*
605.782 Web Application Development with Java*
605.784 Enterprise Computing with Java*
605.785 Web Services with SOAP and REST: Frameworks, Processes, and Applications*
605.786 Enterprise System Design and Implementation*
605.787 Rich Internet Applications with Ajax*
605.788 Big Data Processing Using Hadoop*

### HUMAN-COMPUTER INTERACTION

635.461 Principles of Human-Computer Interaction
605.462 Data Visualization
645.450 Foundations of Human Systems Engineering

### INFORMATION MANAGEMENT

635.421 Principles of Decision Support Systems
605.441 Principles of Database Systems*
605.443 The Semantic Web*
605.444 XML Design Paradigms
605.445 Artificial Intelligence*
605.741 Large-Scale Database Systems*
605.744 Information Retrieval*

### NETWORK ENGINEERING

635.411 Principles of Network Engineering
635.711 Advanced Topics in Network Engineering
605.772 Network and Security Management

*For students with appropriate backgrounds, the following courses may be taken toward the network engineering track. Advisor approval and permission of the instructor is required.*

605.473 High-Speed Networking Technologies*
605.477 Internetworking with TCP/IP I*
605.478 Cellular Communications Systems*
605.771 Wired and Wireless Local and Metropolitan Area Networks*
605.776 Fourth-Generation Wireless Communications: WiMAX and LTE*
605.777 Internetworking with TCP/IP II*
605.778 Voice Over IP*

### SOFTWARE ENGINEERING

605.401 Foundations of Software Engineering
605.402 Software Analysis and Design
605.404 Object Oriented Programming with C++
605.407 Agile Software Development Methods*
605.408 Software Project Management
605.701 Software Systems Engineering*
605.702 Service-Oriented Architecture*
605.704 Object-Oriented Analysis and Design
605.708 Tools and Techniques of Software Project Management*

** Admission to these courses requires fulfillment of the data structures prerequisite.*

## SYSTEMS ENGINEERING

635.401 Foundations of Information Systems Engineering
645.450 Foundations of Human Systems Engineering
645.462 Introduction to Systems Engineering
645.467 Management of Systems Projects
645.742 Management of Complex Systems
645.753 Enterprise Systems Engineering
645.757 Foundations of Modeling and Simulation in Systems Engineering
645.761 Systems Architecting
645.767 System Conceptual Design
645.771 System of Systems Engineering
595.460 Introduction to Project Management
595.792 Management of Innovation

## INDEPENDENT STUDY AND SPECIAL TOPICS

635.795 Information Systems Engineering Capstone Project
635.801 Independent Study in Information Systems Engineering I
635.802 Independent Study in Information Systems Engineering II

*For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.*

*Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.*

# MATERIALS SCIENCE AND ENGINEERING

- **Master of Materials Science and Engineering**
  *Concentration*: Nanotechnology
  *Focus Areas*: Biotechnology or Nanomaterials

The part-time Materials Science and Engineering program allows students to take courses that encourage active research programs in biomaterials, electrochemistry, electronic materials, mechanics of materials, nanomaterials and nanotechnology, physical metallurgy, and thin films.

Courses are offered the Applied Physics Laboratory, the Dorsey Center and at the Homewood campus.

## PROGRAM COMMITTEE

**ROBERT C. CAMMARATA, PROGRAM CHAIR**
Professor, Materials Science and Engineering, JHU Whiting School of Engineering

**DAWNIELLE FARRAR**
Senior Professional Staff, JHU Applied Physics Laboratory

**JENNIFER SAMPLE**
Senior Professional Staff, JHU Applied Physics Laboratory

**JAMES B. SPICER**
Professor, Materials Science and Engineering, JHU Whiting School of Engineering

# REQUIREMENTS

## MASTER'S DEGREE

### ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include a mathematics sequence through differential equations and courses in general physics and chemistry. This program is best suited to applicants who have received undergraduate degrees in engineering or science. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

### DEGREE REQUIREMENTS

A total of ten courses must be completed within five years. The curriculum consists of two core courses and eight electives (at least one at the 600-level or higher). Courses offered through the Department of Materials Science and Engineering in the full-time program (510.xxx) may count as electives. Students interested in taking the Materials Science and Engineering Project (515.730/731) must get prior approval from the departmental chair. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

*CONCENTRATION*

*NANOTECHNOLOGY*

A total of ten courses must be completed within five years. The curriculum consists of four core courses and six electives (at least one at the 600-level or higher). Courses offered through the Department of Materials Science and Engineering in the full-time program (510.xxx) may count as electives. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

Concentrations are noted on the student's transcript.

# COURSES

## CORE COURSES

515.401 Structure and Properties of Materials
515.402 Thermodynamics and Kinetics of Materials

## COURSES BY FOCUS AREA

The focus areas offered represent related groups of courses that are relevant for students with interests in the selected areas. The focus areas are presented as an aid to students in planning their course schedules and are only applicable to students seeking a Master's degree. They do not appear as official designations on a student's transcript or diploma.

### NANOMATERIALS

*SELECT EIGHT*

510.611 Solid-State Physics*
510.612 Solid-State Physics*
515.730 Materials Science and Engineering Project
515.731 Materials Science and Engineering Project
525.406 Electronic Materials
525.421 Introduction to Electronics and the Solid State I
530.652 Bridging Length Scales in Materials Behavior†
540.439 Polymer Nanocomposites‡
580.442 Tissue Engineering§
580.641 Cellular Engineering§
585.209 Organic Chemistry
585.405 Physiology for Applied Biomedical Engineering
585.406 Physiology for Applied Biomedical Engineering
585.409 Mathematical Methods for Applied Biomedical Engineering
585.608 Biomaterials
585.609 Cell Mechanics
585.610 Biochemical Sensors
585.618 Biological Fluid and Solid Mechanics
615.441 Mathematical Methods for Physics and Engineering
615.746 Nanoelectronics: Physics and Devices
615.747 Sensors and Sensor Systems
615.757 Solid-State Physics

### BIOTECHNOLOGY

*SELECT EIGHT*

510.606 Chemical and Biological Properties of Materials*
510.617 Advanced Topics in Biomaterials*
515.730 Materials Science and Engineering Project
515.731 Materials Science and Engineering Project
545.612 Interfacial Phenomena in Nanostructure Material
580.442 Tissue Engineering¶
580.641 Cellular Engineering*
585.405 Physiology for Applied Biomedical Engineering

** 510.xxx courses are offered through the full-time Department of Materials Science & Engineering.*

*† 530.xxx courses are offered through the full-time Department of Mechanical Engineering.*

*‡ 540.xxx courses are offered through the full-time Department of Chemical & Biomolecular Engineering.*

*§ 580.xxx courses are offered through the full-time Department of Biomedical Engineering.*

*¶ 580.xxx courses are offered through the full-time Department of Biomedical Engineering*

585.406 Physiology for Applied Biomedical Engineering
585.409 Mathematical Methods for Applied Biomedical Engineering
585.608 Biomaterials
585.609 Cell Mechanics
585.610 Biochemical Sensors
585.618 Biological Fluid and Solid Mechanics

## COURSES BY CONCENTRATION

### NANOTECHNOLOGY

*CORE COURSES*

515.401 Structure and Properties of Materials
515.402 Thermodynamics and Kinetics of Materials
515.416 Introduction to Nanotechnology
515.417 Nanomaterials

*Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.*

# MECHANICAL ENGINEERING

- **Master of Mechanical Engineering**
  *Focus Areas*: Manufacturing, Mechanics (Solids or Thermofluids), Robotics and Controls[*]
- **Post-Master's Certificate in Mechanical Engineering**

The part-time Mechanical Engineering program is designed for working engineers who want to enhance their effectiveness in a complex and rapidly evolving technological and organizational environment. The program broadens and strengthens students' understanding of traditional fundamentals, but also introduces them to contemporary applications and technologies.

Courses are offered at the Applied Physics Laboratory, the Dorsey Center, the Homewood campus, and online.

## PROGRAM COMMITTEE

**ANDREA PROSPERETTI, PROGRAM CHAIR**
Charles A. Miller Jr. Distinguished Professor of Mechanical Engineering, JHU Whiting School of Engineering

**MEHRAN ARMAND**
Principal Professional Staff, JHU Applied Physics Laboratory

**GREGORY S. CHIRIKJIAN**
Professor of Mechanical Engineering, JHU Whiting School of Engineering

[*] *A focus area must be chosen for this program.*

# REQUIREMENTS

## MASTER'S

### ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include a bachelor's degree in Mechanical Engineering or a related technical discipline. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students are required to choose a focus area to follow. The curriculum consists of one core course in mathematics, two core courses for the focus area, three courses chosen among those listed for the student's focus area, and four other part-time of full-time courses. At least one computationally oriented course is strongly recommended in lieu of an elective. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

## POST-MASTER'S CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post Master's Certificate in Mechanical Engineering.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Only grades of B- or above can count toward the post-master's certificate. Focus areas are not applicable to students pursuing certificates. Students are free to choose any six courses offered by the Mechanical Engineering program. All course selections are subject to advisor approval.

# COURSES

## CORE COURSES

535.441 Mathematical Methods for Engineers

*This advanced mathematics course must be taken in the first semester of the student's program, unless the advisor explicitly allows the student to do otherwise.*

### RECOMMENDED

*SELECT ONE*

*At least one computationally oriented course is strongly recommended in lieu of an elective.*

535.409 Topics in Data Analysis
535.410 Computational Methods of Analysis
535.431 Introduction to Finite Element Methods
535.432 Applied Finite Elements
565.415 Finite Element Methods

## COURSES BY FOCUS AREA

Students are required to choose one of three focus areas: Mechanics, Manufacturing, or Robotics and Controls. The focus area selected does not appear as an official designation in the student transcript. Each focus area has two required courses; the remaining three courses can be chosen among the other courses listed for that area. Post-master's certificate students are not limited to one focus area but can choose their courses among all the courses offered by the program.

### MECHANICS (SOLIDS)

*REQUIRED CORE COURSES*

535.406 Advanced Strength of Materials
535.423 Intermediate Vibrations

*OTHER COURSES FOR THE FOCUS AREA (SELECT THREE)*

535.409 Topics in Data Analysis
535.412 Intermediate Dynamics
535.427 Computer-Aided Design
535.431 Introduction to Finite Element Methods
535.432 Applied Finite Elements
535.454 Theory and Applications of Structural Analysis
535.460 Precision Mechanical Design
535.484 Modern Polymeric Materials
535.720 Analysis and Design of Composite Structures
535.731 Engineering Materials: Properties and Selection
565.415 Finite Element Methods
585.609 Cell Mechanics
585.618 Biological Fluid and Solid Mechanics
585.620 Orthopedic Biomechanics

## MECHANICS (THERMOFLUIDS)

*REQUIRED CORE COURSES*

535.421 Intermediate Fluid Dynamics
535.433 Intermediate Heat Transfer

*OTHER COURSES FOR THE FOCUS AREA (SELECT THREE)*

535.409 Topics in Data Analysis
535.414 Fundamentals of Acoustics
535.424 Energy Engineering
535.434 Applied Heat Transfer
535.450 Combustion
535.452 Thermal Systems Design and Analysis
535.461 Energy and the Environment
535.636 Applied Computational Fluid Mechanics
535.712 Applied Fluid Dynamics
585.609 Cell Mechanics
585.618 Biological Fluid and Solid Mechanics

## MANUFACTURING

*REQUIRED CORE COURSES*

535.428 Computer-Integrated Design and Manufacturing
535.459 Manufacturing Systems Analysis

*OTHER COURSES FOR THE FOCUS AREA (SELECT THREE)*

535.423 Intermediate Vibrations
535.426 Kinematics and Dynamics of Robots
535.427 Computer-Aided Design
535.433 Intermediate Heat Transfer
535.442 Control Systems for Mechanical Engineering Applications
535.458 Design for Manufacturability
535.460 Precision Mechanical Design
535.472 Advanced Manufacturing Systems
535.484 Modern Polymeric Materials
535.626 Advanced Machine Design
595.460 Introduction to Project Management

## ROBOTICS AND CONTROLS

*REQUIRED CORE COURSES*

535.442 Control Systems for Mechanical Engineering Applications
535.426 Kinematics and Dynamics of Robots

*OTHER COURSES FOR THE FOCUS AREA (SELECT THREE)*

525.409 Continuous Control Systems
525.763 Applied Nonlinear Systems
535.409 Topics in Data Analysis
535.412 Intermediate Dynamics
535.422 Robot Motion Planning
535.423 Intermediate Vibrations
535.427 Computer-Aided Design
535.428 Computer-Integrated Design and Manufacturing
535.445 Digital Control and Systems Applications
535.459 Manufacturing Systems Analysis
535.460 Precision Mechanical Design
535.726 Robot Control

*For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.*

*Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.*

# SPACE SYSTEMS ENGINEERING

- **Master of Science in Space Systems Engineering**

The part-time Space Systems Engineering program offers highly technical courses that teach students the skills that spacecraft systems engineers are required to master for senior-level positions within the aerospace industry. Courses cover conceptual design and systems test and integration, as well as deliver hands-on leadership experience by having students develop spacecraft and space-borne sensors on time and on schedule.

Courses are offered at the Applied Physics Laboratory, in a virtual-live format, and online.

## PROGRAM COMMITTEE

**JOSEPH J. SUTER, ACTING PROGRAM CHAIR**
Principal Professional Staff, JHU Applied Physics Laboratory

**RICHARD M. DAY**
Director, Quality Improvement, Johns Hopkins Hospital

**ELIZABETH J. MITCHELL**
Senior Professional Staff, JHU Applied Physics Laboratory

**JAMES T. (TED) MUELLER**
Principal Professional Staff (retired), JHU Applied Physics Laboratory

**AARON Q. ROGERS**
Senior Professional Staff, JHU Applied Physics Laboratory

**HELMUT SEIFERT**
Principal Professional Staff, JHU Applied Physics Laboratory

**STEPHEN A. SHINN**
Deputy Director, Flight Projects, NASA Goddard Space Flight Center

# REQUIREMENTS

## MASTER OF SCIENCE

### ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include an undergraduate degree in a technical discipline. In addition to this requirement, a minimum of two years of relevant full-time work experience in the field and a detailed work résumé and transcripts from all college studies must be submitted. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

Exceptions to these requirements, based on experience, can be made by the program chair.

### DEGREE REQUIREMENTS

A total of ten courses (at least three at the 700-level) must be completed within five years. The curriculum consists of seven core courses and three electives. Only one grade of C can count toward the master's degree. Two of the core courses are a seminar and a capstone project on the Homewood campus. All course selections are subject to advisor approval.

# COURSES

## CORE COURSES

525.783 Spread-Spectrum Communications
595.740 Assuring Success of Aerospace Programs
645.769 System Test and Evaluation
675.401 Fundamentals of Engineering Space Systems I
675.402 Fundamentals of Engineering Space Systems II
675.701 Space Systems Engineering Technical Seminar
675.710 Space Systems Engineering Capstone Project

## ELECTIVES

*SELECT THREE*

525.416 Communication Systems Engineering
525.440 Satellite Communications Systems
525.445 Modern Navigation Systems
595.414 Project Management in an Earned Value Environment
595.464 Project Planning and Control
595.763 Software Engineering Management
645.462 Introduction to Systems Engineering
645.767 System Conceptual Design
645.768 System Design and Integration
675.721 Space Environment and Space Weather
675.800 Directed Studies in Space Systems Engineering

*For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.*

*Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.*

# SYSTEMS ENGINEERING

- **Master of Science in Systems Engineering**
- **Master of Science in Engineering in Systems Engineering** *(ABET-accredited)*
  *Focus Areas for Master's Degrees*: Biomedical Systems Engineering, Cybersecurity Systems Engineering, Human Systems Engineering, Modeling and Simulation Systems Engineering, Project Management, Software Systems Engineering, or Systems Engineering
- **Post-Master's Certificate in Systems Engineering**
- **Graduate Certificate in Systems Engineering**

The part-time Systems Engineering program provides students with in-depth knowledge and technical skills that prepare them to further their careers within industry and government. The program addresses the needs of engineers and scientists engaged in all aspects of analysis, design, integration, production, and operation of modern systems. Instructors are practicing systems engineers who employ lectures and readings on theory and practice, and present realistic problem scenarios in which students, individually and collaboratively, apply principles, tools, and skills.

Courses are offered online, at the Applied Physics Laboratory, Crystal City Center, the Dorsey Center, Southern Maryland Higher Education Center, and University Center of Northeastern Maryland.

## PROGRAM COMMITTEE

**RONALD R. LUMAN, PROGRAM CHAIR**
Principal Professional Staff, JHU Applied Physics Laboratory

**DAVID FLANIGAN, ACTING VICE CHAIR FOR CLASSROOM AND ONLINE PROGRAMS**
Principal Professional Staff, JHU Applied Physics Laboratory

**LARRY D. STRAWSER, VICE PROGRAM CHAIR FOR PARTNERSHIPS**
Principal Professional Staff, JHU Applied Physics Laboratory

**CHRISTIAN UTARA, PROGRAM QUALITY COORDINATOR**
Associate Director, Naval Air Systems Command–AIR 4.6

**MATTHEW HENRY, CURRICULUM AND RESEARCH COORDINATOR**
Senior Professional Staff, JHU Applied Physics Laboratory

**JAMES COOLAHAN, PARTNERSHIP DEVELOPMENT AND OUTREACH MANAGER**
Principal Professional Staff, JHU Applied Physics Laboratory

**STEVEN M. BIEMER**
Principal Professional Staff, JHU Applied Physics Laboratory

**WILLIAM B. CROWNOVER**
Principal Professional Staff, JHU Applied Physics Laboratory

**CONRAD J. GRANT**
Principal Professional Staff, JHU Applied Physics Laboratory

**BENJAMIN F. HOBBS**
Theodore M. and Kay W. Schad Professor of Environmental Management, JHU Whiting School of Engineering

**JERRY A. KRILL**
Principal Professional Staff, JHU Applied Physics Laboratory

**EDWARD A. SMYTH**
Principal Professional Staff, JHU Applied Physics Laboratory

**A focus area must be chosen for this program.*

# REQUIREMENTS

## MASTER OF SCIENCE

### ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include a degree in a science or engineering field. In addition to this requirement, a minimum of one year of relevant full-time work experience in the field and a detailed work résumé and transcripts from all college studies must be submitted. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

Applicants holding a degree in a technical field from a regionally accredited and Accreditation Board for Engineering and Technology Engineering Accreditation Commission (ABET EAC)-accredited college or university will be considered for the Master of Science in Engineering degree. Students admitted without an ABET-accredited Bachelor of Science or who did not complete the prerequisites to meet ABET-accredited math, science, and engineering design requirements at the Bachelor of Science level will receive a regionally accredited Master of Science degree.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years. At least three courses must be at the 700-level. Students are required to select a focus area to follow. The curriculum consists of five core courses and a combination of core and electives based on the chosen focus area.

Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

## POST-MASTER'S CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post Master's Certificate in Systems Engineering.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. The curriculum consists of four core courses and two electives. The two electives can be two semesters of an independent systems engineering research project leading to a paper suitable for submission for publication in a refereed journal, or two 700-level courses in a program approved by the student's advisor. Only grades of B- or above can count toward the post-master's certificate. Focus areas are not available for students pursing certificates. All course selections are subject to advisor approval.

## GRADUATE CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate level courses, but are not necessarily interested in pursuing a full master's degree, are eligible for the Graduate Certificate in Systems Engineering. Applicants are required to meet the same requirements for admission as the master's degree.

Applicants must have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Significant relevant work experience or a graduate degree in a relevant technical discipline may be considered in lieu of meeting the GPA requirement.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare his or her intention prior to the completing the certificate.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. The curriculum consists of five core courses and one of two elective options. Only grades of B- or above can count toward the graduate certificate. Focus areas are not available for students pursing certificates. All course selections are subject to advisor approval.

# COURSES

## CORE COURSES FOR MASTER'S DEGREES AND GRADUATE CERTIFICATE

645.462 Introduction to Systems Engineering
645.467 Management of Systems Projects
645.767 System Conceptual Design
645.768 System Design and Integration
645.769 System Test and Evaluation

## COURSES BY FOCUS AREA

The focus areas offered represent related groups of courses that are relevant for students with interests in the selected areas. The focus areas are presented as an aid to students in planning their course schedules and are only applicable to students seeking a Master's degree. They do not appear as official designations on a student's transcript or diploma.

## BIOMEDICAL SYSTEMS ENGINEERING

*CORE COURSES*

585.405 Physiology for Applied Biomedical Engineering
585.406 Physiology for Applied Biomedical Engineering
585.409 Mathematical Methods for Applied Biomedical Engineering
645.805 Biomedical Systems Engineering Master's Project

*ELECTIVES (SELECT ONE)*

580.630 Theoretical Neuroscience*
585.408 Medical Sensors and Devices
585.608 Biomaterials
585.634 Biophotonics

## CYBERSECURITY SYSTEMS ENGINEERING

*CORE COURSES*

645.806 Cybersecurity Systems Engineering Master's Project
695.401 Foundations of Information Assurance
695.721 Network Security

*ELECTIVES (SELECT TWO)*

695.411 Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms
695.421 Public Key Infrastructure and Managing E-Security
695.422 Web Security
695.791 Information Assurance Architectures and Technologies

## HUMAN SYSTEMS ENGINEERING

*CORE COURSES*

645.450 Foundations of Human Systems Engineering
645.451 Integrating Humans and Technology
645.808 Human Systems Engineering Master's Project

*ELECTIVES (SELECT TWO)*

635.461 Principles of Human-Computer Interaction
645.754 Social and Organizational Factors in Human Systems Engineering
645.755 Methods in Human-System Performance Measurement and Analysis

## MODELING AND SIMULATION SYSTEMS ENGINEERING

*CORE COURSES*

625.403 Statistical Methods and Data Analysis
645.757 Foundations of Modeling and Simulation in Systems Engineering
645.758 Advanced Systems Modeling Simulation
645.801 Systems Engineering Master's Thesis
645.802 Systems Engineering Master's Thesis

** 580.xxx courses are offered through the full-time Department of Biomedical Engineering.*

## PROJECT MANAGEMENT

*CORE COURSES*

595.461 Technical Group Management
595.465 Communications in Technical Organizations OR
595.466 Financial and Contract Management
645.764 Software Systems Engineering
645.800 Systems Engineering Master's Project

*ELECTIVES (SELECT ONE)*

645.742 Management of Complex Systems
645.753 Enterprise Systems Engineering
645.761 Systems Architecting
645.771 System of Systems Engineering

## SYSTEMS ENGINEERING

*CORE COURSES*

645.764 Software Systems Engineering

*SELECT ONE*

645.742 Management of Complex Systems
645.753 Enterprise Systems Engineering
645.761 Systems Architecting
645.771 System of Systems Engineering Master's Project or Thesis

*SELECT ONE*

645.800 Systems Engineering Master's Project
645.801 Systems Engineering Master's Thesis AND
645.802 Systems Engineering Master's Thesis

*ELECTIVES (SELECT ONE–TWO BASED ON COURSE SELECTION ABOVE)*

645.469 Systems Engineering of Deployed Systems
645.756 Metrics, Modeling, and Simulation for Systems Engineering

*Selections from Applied Biomedical Engineering; Applied Physics; Computer Science; Electrical and Computer Engineering; Information Systems Engineering; Technical Management; and Environmental Engineering, Science, and Management may also be chosen.*

## SYSTEMS ENGINEERING SOFTWARE

*CORE COURSES*

605.401 Foundations of Software Engineering
605.402 Software Analysis and Design
645.807 Software Systems Engineering Master's Project

*ELECTIVES (SELECT TWO)*

605.407 Agile Software Development Methods
605.411 Foundations of Computer Architecture
605.701 Software Systems Engineering
605.705 Software Safety
605.708 Tools and Techniques of Software Project Management
695.421 Public Key Infrastructure and Managing e-Security
695.422 Web Security

## COURSES FOR POST-MASTER'S CERTIFICATE

*REQUIRED*

645.742 Management of Complex Systems
645.753 Enterprise Systems Engineering
645.761 Systems Architecting
645.771 System of Systems Engineering

*ELECTIVES (SELECT ONE)*

645.803 Post-Master's Systems Engineering Research Project *AND*
645.804 Post-Master's Systems Engineering Research Project

Two approved 700-level courses

*For state-specific information for online programs, see the Online Education State Authorization Application Policy section on page 3.*

*Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.*

# TECHNICAL MANAGEMENT

- **Master of Science in Technical Management**
  *Focus Areas*: Organizational Management, Project Management, Project/Organizational Management, Quality Management, Technical Innovation Management*
- **Post-Master's Certificate in Technical Management**
- **Graduate Certificate in Technical Management**

The part-time Technical Management program prepares those trained and experienced in science or engineering to lead technical projects, and to organize and supervise technical personnel. The program blends lectures on theory and practice presented by experienced technical senior leaders and executives. Realistic problem situations are presented in which students play management roles, dealing with problems and making decisions that are typically required of technical managers. Emphasis is on the blend of technical, administrative, business, and interpersonal skills required for the successful management of continuously changing high-technology organizations and projects.

Courses are offered at the Applied Physics Laboratory, Dorsey Center, in a virtual-live format, and online.

## PROGRAM COMMITTEE

JOSEPH J. SUTER, PROGRAM CHAIR
Principal Professional Staff, JHU Applied Physics Laboratory

JAMES T. (TED) MUELLER, VICE CHAIR
Principal Professional Staff (retired), JHU Applied Physics Laboratory

RICHARD W. BLANK, PROGRAM COORDINATOR
Principal Professional Staff, JHU Applied Physics Laboratory

SHARON B. ALAVI-HANTMAN
Principal Attorney, Avail Law, LLC

ALTON D. HARRIS, III
General Engineer, Office of Disposal Operations, Environmental Management, US Department of Energy

ANN E. KEDIA
Senior Professional Staff, JHU Applied Physics Laboratory

STANISLAW E. TARCHALSKI
Director (retired), IBM Corporation

JUDITH G. THEODORI
Principal Professional Staff,JHU Applied Physics Laboratory

**A focus area must be chosen for this program.*

# REQUIREMENTS

## MASTER OF SCIENCE

### ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 5. The applicant's prior education must include a degree in a science or engineering field. In addition to this requirement, a minimum of two years of relevant full-time work experience in the field and a detailed work résumé and transcripts from all college studies must be submitted. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

### DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students must choose a focus area to follow. The curriculum consists of a combination of core and electives based on the chosen focus area; at least three of which must be 700-level courses. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

## POST-MASTER'S CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post Master's Certificate in Technical Management.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least four of the six courses must be from the program (595.xxx). Two electives may be taken from other programs with approval from the program chair or vice chair. Only grades of B- or above can count toward the post-master's certificate. Focus areas are not available for students pursing certificates. All course selections are subject to advisor approval.

## GRADUATE CERTIFICATE

### ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate level courses, but are not necessarily interested in pursuing a full master's degree, are eligible for the Graduate Certificate in Technical Management. Applicants are required to meet the same requirements for admission as the master's degree.

Applicants must have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Significant relevant work experience or a graduate degree in a relevant technical discipline may be considered in lieu of meeting the GPA requirement.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare his or her intention prior to the completing the certificate.

### CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least four of the six courses must be from the program (595.xxx). Two electives may be taken from other programs with approval from the program chair or vice chair. Only grades of B- or above can count toward the graduate certificate. Focus areas are not available for students pursing certificates. All course selections are subject to advisor approval.

# COURSES

## CORE COURSES

Students are required to take the core courses listed in their focus areas. Electives will round out the ten course requirement.

## COURSES BY FOCUS AREA

The focus areas offered represent related groups of courses that are relevant for students with interests in the selected areas. The focus areas are presented as an aid to students in planning their course schedules and are only applicable to students seeking a Master's degree. They do not appear as official designations on a student's transcript or diploma.

## ORGANIZATIONAL MANAGEMENT

*CORE COURSES*

595.460 Introduction to Project Management
595.461 Technical Group Management
595.463 Technical Personnel Management
595.464 Project Planning and Control
595.465 Communications in Technical Organizations
595.466 Financial and Contract Management
595.762 Management of Technical Organizations

***Plus three** electives (two at the 700-level).*

## PROJECT MANAGEMENT

*CORE COURSES*

595.460 Introduction to Project Management
595.461 Technical Group Management
595.464 Project Planning and Control
595.465 Communications in Technical Organizations
595.466 Financial and Contract Management
595.763 Software Engineering Management
645.462 Introduction to Systems Engineering

***Plus three** electives (two at the 700-level).*

## PROJECT/ORGANIZATIONAL MANAGEMENT

*CORE COURSES*

595.460 Introduction to Project Management
595.461 Technical Group Management
595.463 Technical Personnel Management
595.464 Project Planning and Control
595.465 Communications in Technical Organizations
595.466 Financial and Contract Management
595.762 Management of Technical Organizations
595.763 Software Engineering Management
645.462 Introduction to Systems Engineering

***Plus one** 700-level elective.*

## QUALITY MANAGEMENT

*CORE COURSES*

595.460 Introduction to Project Management
595.464 Project Planning and Control
595.740 Assuring Success of Aerospace Programs
595.742 Foundations of Quality Management
595.763 Software Engineering Management
645.462 Introduction to Systems Engineering

***Plus four** electives.*

## TECHNICAL INNOVATION MANAGEMENT

*CORE COURSES*

595.460 Introduction to Project Management
595.461 Technical Group Management
595.465 Communications in Technical Organizations
595.466 Financial and Contract Management
595.468 Fundamentals of Technical Innovation in Organizations
595.762 Management of Technical Organizations
595.766 Advanced Technology
595.792 Management of Innovation

***Plus two** electives.*

## ELECTIVES

595.414 Project Management in an Earned Value Environment
595.461 Technical Group Management
595.463 Technical Personnel Management
595.464 Project Planning and Control
595.465 Communications in Technical Organizations
595.466 Financial and Contract Management
595.467 Principles of Agile Methods in Project Management
595.468 Fundamentals of Technical Innovation in Organizations
595.731 Business Law for Technical Professionals
595.740 Assuring Success of Aerospace Programs
595.742 Foundations of Quality Management
595.762 Management of Technical Organizations
595.763 Software Engineering Management
595.766 Advanced Technology
595.781 Executive Technical Leadership
595.792 Management of Innovation
595.802 Directed Studies in Technical Management
645.767 System Conceptual Design
645.768 System Design and Integration
645.769 System Test and Evaluation

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*Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.*

# COURSE DESCRIPTIONS

*For state-specific information for online programs, see the Online Education State Authorization section on page 3.*

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## MATERIALS SCIENCE AND ENGINEERING

### 515.401 Structure and Properties of Materials

Topics include types of materials, bonding in solids, basic crystallography, crystal structures, tensor properties of materials, diffraction methods, crystal defects, and amorphous materials.

**Instructor**: Faculty

### 515.402 Thermodynamics and Kinetics of Materials

Topics include laws of thermodynamics, equilibrium of single and multiphase systems, chemical thermodynamics, statistical thermodynamics of solid solutions, equilibrium phase diagrams,
chemical kinetics, diffusion in solids, nucleation and growth processes, coarsening, and glass transition.

**Instructor**: Faculty

### 515.416 Introduction to Nanotechnology

Nanoscale science and nanotechnology are broad interdisciplinary areas, encompassing not just materials science but everything from biochemistry to electrical engineering and more. This will be a survey course introducing some of the fundamental principles behind nanotechnology and nanomaterials, as well as applications of nanotechnology. The role of solid-state physics and chemistry in nanotechnology will be emphasized. Nanoscale tools such as surface probe and atomic force microscopy and nanolithography, as well as special topics such as molecular electronics, will also be covered.

**Instructor**: Sample

### 515.417 Nanomaterials

Nanomaterials is a survey course that covers concepts and the associated relevant physics and materials science of what makes nanoscale materials so unique. We will learn about nanoscale characterization (electron and probe microscopy), fabrication at the nanoscale (self-assembly and top-down fabrication), and many current applications of nanomaterials across broad areas from medicine to defense. This course will take an in-depth look at nanomaterials discussed in Introduction to Nanotechnology; however, it stands alone with no prerequisite.

**Instructors**: Sample, Zhang

### 515.730 Materials Science and Engineering Project

This course is an individually tailored, supervised project that offers research experience through work on a special problem related to each student's field of interest. Upon completion of this course, a written essay must be submitted. Final approval of the essay will be given by the faculty advisor.

**Prerequisites**: All other course work should be completed before this project begins (or at least completed concurrently with this project). Consent of advisor is required.

**Course Note**: This course is available only to students in the Master of Materials Science and Engineering program.

**Instructor**: Faculty

### 515.731 Materials Science and Engineering Project

This course is an individually tailored, supervised project that offers research experience through work on a special problem related to each student's field of interest. Upon completion of this course, a written essay must be submitted. Final approval of the essay will be given by the faculty advisor.

**Prerequisites**: All other course work should be completed before this project begins (or at least completed concurrently with this project). Consent of advisor is required.

**Course Note**: This course is available only to students in the Master of Materials Science and Engineering program.

**Instructor**: Faculty

## ELECTRICAL AND COMPUTER ENGINEERING

### 525.201 Circuits, Devices, and Fields

This course is intended to prepare students lacking an appropriate background for graduate study in electrical and computer engineering. Fundamental mathematical concepts including calculus, differential equations, and linear algebra are reviewed. Circuit theory for linear and nonlinear devices and components is covered. An introduction to electricity and magnetism is presented along with basic wave propagation theory. Finally, Boolean algebra is studied with applications to digital circuit design and analysis.

**Course Note**: Not for graduate credit.

**Instructor**: Faculty

**525.202 Signals and Systems**

This course is intended to prepare students lacking an appropriate background for graduate study in electrical and computer engineering. Signal and system representations and analysis tools in both continuous time and discrete time are covered. Linear time-invariant systems are defined and analyzed. The Fourier transform, the Laplace transform, and the z-transform are treated along with the sampling theorem. Finally, fundamental concepts in probability, statistics, and random processes are considered.

**Course Note**: Not for graduate credit.

**Instructors**: Edwards, Jennison

**525.405 Intermediate Electromagnetics**

This course provides a background in engineering electromagnetics required for more advanced courses in the field. Topics include vector calculus, Poisson's and Laplace's equations, vector potentials, Green's functions, magnetostatics, magnetic and dielectric materials, Maxwell's equations, plane wave propagation and polarization, reflection and refraction at a plane boundary, frequency-dependent susceptibility functions, transmission lines, waveguides, and simple antennas. Practical examples are used throughout the course.

**Instructors**: Thomas, Weiss

**525.406 Electronic Materials**

Materials and the interfaces between them are the key elements in determining the functioning of electronic devices and systems. This course develops the fundamental parameters of the basic solid material types and their relationships to electrical, thermal, mechanical, and optical properties. The application of these materials to the design and fabrication of electronic components is described, including integrated circuits, passive components, and electronic boards, modules, and systems.

**Prerequisites**: An undergraduate degree in engineering, physics, or materials science; familiarity with materials structures and electronic devices.

**Instructor**: Charles

**525.407 Introduction to Electronic Packaging**

Topics include fundamentals of electronic packaging engineering and basic concepts in thermal, mechanical, electrical, and environmental management of modern electronic systems. Emphasis is on high-frequency (and high-speed) package performance and its achievement through the use of advanced analytical tools, proper materials selection, and efficient computer-aided design. Packaging topics include die and lead attachment, substrates, hybrids, surface-mount technology, chip and board environmental protection, connectors, harnesses, and printed and embedded wiring boards.

**Prerequisite**: An undergraduate degree in a scientific or engineering area, including familiarity with computer-aided design and engineering analysis methods for electronic circuits and systems.

**Instructor**: Charles

**525.408 Digital Telephony**

This course examines communication techniques for the transmission in voice of various channels. Topics include characteristics of speech and voice digitization; bandwidth minimization and voice compression; digital modulation and standards; transmission via fiber, terrestrial microwave, and satellite channels; cellular telephone architectures and networks; and digital switching architectures and networks.

**Prerequisite**: Either an undergraduate degree in electrical engineering or 525.416 Communication Systems Engineering, or consent of the instructor.

**Instructors**: Blodgett, Carmody

**525.409 Continuous Control Systems**

This course examines classical methods of analysis and design of continuous control systems. Topics include system representation by linear time invariant ordinary differential equations, performance measures, sensitivity, stability, root locus, frequency domain techniques, and design methods. Several practical examples are considered. MATLAB is used as a computational tool.

**Prerequisites**: Matrix Theory and Linear Differential Equations.

**Instructor**: Palumbo

**525.410 Microprocessors for Robotic Systems**

This course examines microprocessors as an integral part of robotic systems. Techniques required for successful incorporation of embedded microprocessor technology are studied and applied to robotic systems. Students will use hardware in a laboratory setting and will develop software that uses features of the microprocessor at a low level to accomplish the real-time performance necessary in robotic applications. Topics will include microprocessor selection, real-time constraints, sensor interfacing, actuator control, and system design considerations.

**Prerequisites**: Experience with C programming and a course in digital systems or computer architecture.

**Instructors**: Golden, Sawyer

**525.412 Computer Architecture**

This course focuses on digital hardware design for all major components of a modern, reduced-instruction-set computer. Topics covered include instruction set architecture; addressing modes; register-transfer notation; control circuitry; pipelining with hazard control; circuits to support interrupts and other exceptions; microprogramming; computer addition and subtraction circuits using unsigned, two's-complement, and excess notation; circuits to support multiplication using Robertson's and Booth's algorithms; circuits for implementing restoring and nonrestoring division; square-root circuits; floating-point arithmetic notation and circuits; memory and cache memory systems; segmentation and paging; input/output interfaces; interrupt processing; direct memory access; and several common peripheral devices, including analog-to-digital and digital-to-analog converters.

**Prerequisite**: An undergraduate course in digital design.

**Instructor**: Beser

**525.413 Fourier Techniques in Optics**

In this course, the study of optics is presented from a perspective that uses the electrical engineer's background in Fourier analysis and linear systems theory. Topics include scalar diffraction theory, Fourier transforming and imaging properties of lenses, spatial frequency analysis of optical systems, spatial filtering and information processing, and holography. The class discusses applications of these concepts in nondestructive evaluation of materials and structures, remote sensing, and medical imaging.

**Prerequisites**: An undergraduate background in Fourier analysis and linear systems theory.

**Instructor**: Young

**525.414 Probability and Stochastic Processes for Engineers**

This course provides a foundation in the theory and applications of probability and stochastic processes and an understanding of the mathematical techniques relating to random processes in the areas of signal processing, detection, estimation, and communication. Topics include the axioms of probability, random variables, and distribution functions; functions and sequences of random variables; stochastic processes; and representations of random processes.

**Prerequisite**: An undergraduate degree in electrical engineering.

**Instructors**: Ambrose, Fry, Murphy

**525.415 Embedded Microprocessor Systems**

This course applies microprocessors as an integral element of system design. Techniques required for successful incorporation of microprocessor technology are studied and used. Hardware and software design considerations that affect product reliability, performance, and flexibility are covered. Students use hardware to gain familiarity with machine and assembly language for software generation, interfacing to a microprocessor at the hardware level, and emulation to check out system performance. Topics include security in embedded systems, case studies in system failures, embedded processors in the space environment, communications protocols, hardware/software system trade-offs, and SoC/FPGA designs. The course is based on the ARM architecture, and the student will do a series of development and interfacing labs.

**Prerequisites**: Some experience in designing and building digital electronic systems, some familiarity with C programming, and a course in digital systems.

**Instructor**: Stakem

**525.416 Communication Systems Engineering**

In this course, students receive an introduction to the principles, performance, and applications of communication systems. Students examine analog modulation/demodulation systems (amplitude—AM, DSB, and SSB; and angle—PM and FM) and digital modulation/demodulation systems (binary and M-ary) in noise and interference. Subtopics include filtering, sampling, quantization, encoding, and the comparison of coherent and noncoherent detection techniques to improve signal-to-noise ratio (SNR) and bit error rate (BER) performance. Special topics and/or problems will be assigned that provide knowledge of how communication systems work from a systems engineering viewpoint in real-world environments.

**Prerequisites**: A working knowledge of Fourier transforms, linear systems, and probability theory. Knowledge of a numerical software package such as MATLAB or MATHCAD is recommended.

**Instructors**: Alexander, Marble, Nichols

**525.418 Antenna Systems**

This course introduces and explains fundamental antenna concepts for both antennas and antenna arrays. Electromagnetic theory is reviewed and applied to antenna elements such as dipoles, loops, and aperture antennas, as well as antenna arrays. Antenna analysis is presented from a circuit theory point of view to highlight concepts such as reciprocity and the implications for transmit and receive radiation patterns. The importance of two-dimensional Fourier transforms is explained and applied to aperture antennas. Basic array constraints are examined through case studies of uniform, binomial, and general amplitude distributions. The concept of beam squint is explained through examination of constant-phase versus constant-time phase shifters. The Rotman lens is discussed as an example of a common beamformer. The class concludes with an explanation of antenna measurements.

**Prerequisite**: 525.405 Intermediate Electromagnetics or 615.442 Electromagnetics or permission of the instructor

**Instructor**: Weiss

### 525.419 Introduction to Digital Image and Video Processing

This course provides an introduction to the basic concepts and techniques used in digital image and video processing. Two-dimensional sampling and quantization are studied, and the human visual system is reviewed. Edge detection and feature extraction algorithms are introduced for dimensionality reduction and feature classification. High-pass and bandpass spatial filters are studied for use in image enhancement. Applications are discussed in frame interpolation, filtering, coding, noise suppression, and video compression. Some attention will be given to object recognition and classification, texture analysis in remote sensing, and stereo machine vision.

**Prerequisite**: 525.427 Digital Signal Processing.

**Instructor**: Nasrabadi

### 525.420 Electromagnetic Transmission Systems

This course examines transmission systems used to control the propagation of electromagnetic traveling waves with principal focus emphasizing microwave and millimeter-wave applications. The course reviews standard transmission line systems together with Maxwell's equations and uses them to establish basic system concepts such as reflection coefficient, characteristic impedance, input impedance, impedance matching, and standing wave ratio. Specific structures are analyzed and described in terms of these basic concepts, including coaxial, rectangular, and circular waveguides, surface waveguides, striplines, microstrips, coplanar waveguides, slotlines, and finlines. Actual transmission circuits are characterized using the concepts and analytical tools developed.

**Prerequisites**: Students must have knowledge of material covered in 525.201 Circuits, Devices, and Fields and 525.202 Signals and Systems or must have taken a course on intermediate electromagnetics equivalent to 525.405 Intermediate Electromagnetics.

**Instructor**: Sequeira

### 525.421 Introduction to Electronics and the Solid State I

Fundamentals of solid-state and device physics are presented. Topics in solid-state physics include crystal structure, lattice vibrations, dielectric and magnetic properties, band theory, and transport phenomena. Concepts in quantum and statistical mechanics are also included. Basic semiconductor device operation is described with emphasis on the p-n junction.

**Prerequisite**: An undergraduate degree in electrical engineering or the equivalent.

**Instructor**: Charles

### 525.422 Introduction to Electronics and the Solid State II

This course reviews the fundamentals of device physics and electronics. Topics in device electronics include bipolar and MOS transistors, Schottky barriers, transferred electron and tunnel devices, semiconductor lasers, and solar cells. Concepts in device structure, modeling, and performance are described.

**Prerequisite**: 525.421 Introduction to Electronics and the Solid State I or approval of the instructor.

**Instructor**: Charles

### 525.423 Principles of Microwave Circuits

This course addresses foundational microwave circuit concepts and engineering fundamentals. Topics include electromagnetics leading to wave propagation and generation, the transmission line, and impedance/admittance transformation and matching. Mapping and transformation are presented in the development of the Smith Chart. The Smith Chart is used to perform passive microwave circuit design. Microwave networks and s-matrix are presented; Mason's rules are introduced. Circuits are physically designed using microstrip concepts, taking into consideration materials properties, connectors, and other components.

**Instructor**: Abita

### 525.424 Analog Electronic Circuit Design I

This course examines the use of passive and active components to perform practical electronic functions. Simple circuits are designed and evaluated, emphasizing the characteristics and tolerances of actual components. Devices studied include diodes and bipolar and field effect transistors. Circuit designs are studied in relation to the device characteristics, including small signal amplifiers and oscillators, and linear power supply and amplifier circuits. SPICE modeling is available to students.

**Prerequisites**: Undergraduate courses in electricity and magnetism, circuit theory, and linear analysis.

**Instructors**: Baisden, Darlington

**525.425 Laser Fundamentals**

This course reviews electromagnetic theory and introduces the interaction of light and matter, with an emphasis on laser theory. A fundamental background is established, necessary for advanced courses in optical engineering. Topics include Maxwell's equations, total power law, introduction to spectroscopy, classical oscillator model, Kramers–Kroenig relations, line broadening mechanisms, rate equations, laser pumping and population inversion, laser amplification, laser resonator design, and Gaussian beam propagation.

**Prerequisite**: 525.405 Intermediate Electromagnetics or equivalent.

**Instructors**: Thomas, Willitsford

**525.427 Digital Signal Processing**

Basic concepts of discrete linear shift-invariant systems are emphasized, including sampling, quantization, and reconstruction of analog signals. Extensive coverage of the Z-transform, discrete Fourier transform, and fast Fourier transform is given. An overview of digital filter design includes discussion of impulse invariance, bilinear transform, and window functions. Filter structures, finite length register effects, roundoff noise, and limit cycles in discrete-time digital systems are also covered.

**Prerequisites**: A working knowledge of Fourier and Laplace transforms.

**Instructors**: Ambrose, C. L. Edwards, M. L. Edwards, Jennison, R. Lee

**525.428 Introduction to Digital CMOS VLSI**

The objective of this course is to familiarize the student with the process of implementing a digital system as a full custom, integrated circuit. Upon completion, the student will be capable of completing skills to perform basic VLSI design from circuit concept to mask layout and simulation. Students will have the opportunity to have their projects fabricated at no cost through the MOSIS educational program. Topics include device fabrication, mask layout, introductory MOSFET physics, standard CMOS logic design, hierarchical IC design, and circuit simulation. Students will design, simulate, and do mask-level layout of a circuit using a modern CMOS process.

**Prerequisite**: A course in digital design.

**Instructor**: Meitzler

**525.430 Digital Signal Processing Lab**

This course builds on the theory of digital signal processing. Opportunities are provided to work on specific applications of digital signal processing involving filtering, deconvolution, spectral estimation, and a variety of other techniques. Students may also suggest their own laboratory topics. Laboratory work involves developing signal processing systems on a personal computer and using them with both real and simulated data. Questions related to hardware realizations are also considered.

**Prerequisite**: 525.427 Digital Signal Processing.

**Instructors**: Fry

**525.431 Adaptive Signal Processing**

This course examines adaptive algorithms (LMS, sequential regression, random search, etc.) and structures (filters, control systems, interference cancellers), as well as properties and uses of performance surfaces. Adaptive systems are implemented as part of the course work. Problem exercises and a term project require computer use.

**Prerequisites**: 525.427 Digital Signal Processing. Some knowledge of probability is helpful.

**Instructor**: Costabile

**525.432 Analog Electronic Circuit Design II**

This course extends the fundamental concepts of practical electronic circuit design developed in the course 525.424 Analog Electronic Circuit Design I. The general feedback method is reviewed. Students examine a wide range of devices, including operational amplifiers, A/D and D/A converters, switching regulators, and power supplies. Applications include low noise amplification, sensor conditioning, nonlinear transfer functions and analog computation, and power control.

**Prerequisite**: 525.424 Analog Electronic Circuit Design I or permission of the instructor.

**Instructors**: Baisden, Darlington

**525.434 High-Speed Digital Design and Signal Integrity**

This course will discuss the principles of signal integrity and its applications in the proper design of high-speed digital circuits. Topics include the following: the definition and fundamentals of signal integrity, the fallacies believed by digital designers, ground/ power planes, PCI series termination resistors, simulation software and signal integrity, ground bounce calculations, power bus noise, high-speed return signals, transmission lines, gate delay, differential pair skew, bypass capacitor layout, cable shield grounding, power-ground source impedance, open drain lines, series termination, equivalent circuit source impedance, terminators, crosstalk and SSO noise, gigabit Ethernet specification, and short transmission line model.

**Prerequisites**: Thorough knowledge of digital design and basic circuit theory.

**Instructor**: Eaton

**525.436 Optics and Photonics Laboratory** 🏛

The objective of this course is to develop laboratory skills in optics and photonics by performing detailed experimental measurements and comparing these measurements to theoretical models. Error analysis is used throughout to emphasize measurement accuracy. A partial list of topics includes geometric optics, optical properties of materials, diffraction, interference, polarization, nonlinear optics, fiber optics, nonlinear fiber optics, optical detectors (pin, APD, PMT), optical sources (lasers, blackbodies, LEDs), phase and amplitude modulators, lidar, fiber-optic communications, and IR radiometry. The specific experiments will depend on hardware availability and student interest.

**Prerequisite**: 525.405 Intermediate Electromagnetics or equivalent or permission of the instructor.

**Instructor**: Sova

**525.438 Introduction to Wireless Technology** 🔀

This course introduces students to the modern technology involved with commercial wireless communications systems such as digital cellular, personal communications systems (PCS), wireless local area networks (WLAN), code division multiple access (CDMA) systems, and other topics. Various multiple access methods and signal formats are considered. Hardware implementations of system components are presented and analyzed. Modulation and demodulation architectures are introduced and modeled using PC-based tools.

**Prerequisites**: An undergraduate degree in electrical engineering or the equivalent. Experience with MATLAB and Simulink will be helpful.

**Instructor**: Roddewig

**525.440 Satellite Communications Systems** 🏛

This course presents the fundamentals of satellite communications link design and provides an overview of practical considerations. Existing systems are described and analyzed, including direct broadcast satellites, VSAT links, and Earth-orbiting and deep-space spacecraft. Topics include satellite orbits, link analysis, antenna and payload design, interference and propagation effects, modulation techniques, coding, multiple access, and Earth station design.

**Prerequisite**: 525.416 Communication Systems Engineering.

**Instructors**: Carmody, DeBoy

**525.441 Computer and Data Communication Networks I** 🏛

This course provides a comprehensive overview of computer and data communication networks, with emphasis on analysis and modeling. Basic communications principles are reviewed as they pertain to communication networks. Networking principles covered include layered network architecture, data encoding, static and multi-access channel allocation methods (for LAN and WAN), ARQ retransmission strategies, framing, routing strategies, transport protocols, and emerging high-speed networks.

**Prerequisites**: 525.414 Probability and Stochastic Processes for Engineers and 525.416 Communication Systems Engineering, or equivalents.

**Instructors**: Hanson, Nasrabadi

**525.442 FPGA Design Using VHDL** 🔀

This lab-oriented course covers the design of digital systems using VHSIC Hardware Description Language (VHDL) and its implementation in field-programmable gate arrays (FPGAs). This technology allows cost-effective, unique system realizations by enabling design reuse and simplifying custom circuit design. The design tools are first introduced and used to implement basic circuits. More advanced designs follow, focusing on integrating the FPGA with external peripherals, simple signal processing applications, utilizing soft-core processors, and using intellectual property (IP) cores.

**Prerequisite**: A solid understanding of digital logic fundamentals.

**Instructors**: DuBois, Hourani, Meitzler

**525.443 Real-Time Computer Vision** 🏛

This course introduces students to real-time computer vision through intensive use of the OpenCV open source computer vision framework. Students will learn to quickly build applications that enable computers to "see" and make decisions based on the video stream input from a camera. Through regular assignments and in-class laboratory exercises (students are advised to bring their own laptop in class), students will build real-time systems for performing object recognition, face detection and recognition. Key computer vision topics addressed in the course include: human and machine vision: how does the brain recognize objects, and what can we emulate; camera models and camera calibration; edge, line and contour detection; optical flow and object tracking; machine learning techniques; image features and object recognition; stereo vision, 3D vision, Kinect sensing and range images; face detection and face recognition. Students will be exposed to the mathematical tools that are most useful in the implementation of computer vision algorithms (prior knowledge of linear algebra, geometry and probability theory is desired).

**Prerequisite**: Some prior programming experience using C, C++, or Python is required.

**Instructors**: Burlina, Drenkow

**525.445 Modern Navigation Systems**

This course explores the use of satellite, terrestrial, celestial, radio, magnetic, and inertial systems for the real-time determination of position, velocity, acceleration, and attitude. Particular emphasis is on the historical importance of navigation systems; avionics navigation systems for high-performance aircraft; the Global Positioning System; the relationships between navigation, cartography, surveying, and astronomy; and emerging trends for integrating various navigation techniques into single, tightly coupled systems.

**Instructor**: Jablonski

**525.446 DSP Hardware Lab**

This course develops expertise and insight into the development of DSP processor solutions to practical engineering problems through hands-on experience. Structured exercises using DSP hardware are provided and used by the student to gain practical experience with basic DSP theory and operations. Course focus is on real-time, floating-point applications. This course is intended for engineers having EE or other technical backgrounds who desire to obtain practical experience and insight into the development of solutions to DSP problems requiring specialized DSP architectures.

**Prerequisites**: 525.427 Digital Signal Processing and C programming experience.

**Instructors**: Haber, Wenstrand

**525.448 Introduction to Radar Systems**

This class introduces the student to the fundamentals of radar systems engineering. The radar range equation in its many forms is developed and applied to different situations. Radar transmitters, antennas, and receivers are covered. The concepts of matched filtering, pulse compression, and the radar ambiguity function are introduced, and the fundamentals of radar target detection in a noise background are discussed. Target radar cross-section models are addressed, as well as the effects of the operating environment, including propagation and clutter. MTI and pulsed Doppler processing and performance are addressed. Range, angle, and Doppler resolution/accuracy, as well as fundamental tracking concepts, will also be discussed.

**Prerequisites**: 525.414 Probability and Stochastic Processes for Engineers, 525.427 Digital Signal Processing, a working knowledge of electromagnetics, and familiarity with MATLAB.

**Instructors**: Farthing, Griffith, Lum

**525.451 Introduction to Electric Power Systems**

This course introduces and explains fundamentals of electrical power systems design and engineering. Phasors and their application to power systems analysis are reviewed. The concept of the per-unit system is introduced and applied to circuit calculations. Transformers and their application to electrical power transmission and distribution systems will be covered. Transmission line parameters, their calculation, and transmission line modeling are introduced. Power flow analysis computational techniques are covered. Short-circuit analysis and the method of symmetrical components are introduced. The concept of power system protection and the role of automatic relays will be covered. Transient stability of power systems will be discussed. Renewable energy generation and the integration of renewable energy into the modern power grid will be introduced.

**Prerequisites**: Course in electrical networks and a course in linear algebra and matrix operations.

**Instructor**: Alvandi

**525.454 Communications Circuits Laboratory**

This online laboratory-based course focuses on modulation/demodulation (MODEM) aspects of wireless communications systems. This course is designed to enhance the student's understanding of fundamental communications waveforms and to present methods commonly used to process them. Students will be exposed to various implementations of MODEM circuits used to process waveforms such as FM, FSK, PSK, and QAM. All work is performed remotely via internet access to the remote laboratory facility located at the Johns Hopkins University. Following an introduction to this remote laboratory implementation, students will conduct a series of laboratory exercises designed to enhance their understanding of material presented in communications engineering courses. Course modules involve the characterization of waveforms and MODEM circuits through lecture, laboratory exercises, analysis, and online discussion. Material required for this course include a broadband internet connection, web browser, word processing software (e.g. MS Word or equivalent), and analysis software (e.g. Matlab or equivalent) used to process and present data collected.

**Prerequisite**: 525.416 Communication Systems Engineering or consent of the instructor.

**Instructor**: Houser

**525.461 UAV Systems and Control**

This hardware-supplemented course covers the guidance, navigation and control principles common to many small fixed-wing and multirotor unmanned aerial vehicles (UAVs). Building upon classical control systems and modeling theory, students will learn how to mathematically model UAV flight characteristics and sensors, develop and tune feedback control autopilot algorithms to enable stable flight control, and fuse sensor measurements using extended Kalman filter techniques to estimate the UAV position and orientation. Students will realize these concepts through both simulation and interaction with actual UAV hardware. Throughout the course, students will build a full 6-degree-of-freedom simulation of controlled UAV flight using MATLAB and Simulink. Furthermore, the students will reinforce their UAV flight control knowledge by experimenting with, tuning, and flying actual open-source quadrotor UAVs.

**Prerequisites**: Background in control systems (e.g. 525.409 Continuous Control Systems) and matrix theory along with a working knowledge of MATLAB. Experience using Simulink is desired. Existing familiarity with C programming language, electronics and microcontrollers will be helpful but is not required.

**Instructors**: Barton, Castelli

### 525.466 Linear System Theory

This course covers the structure and properties of linear dynamic systems, with an emphasis on the single-input, single-output case. Topics include the notion of state-space, state variable equations, review of matrix theory, linear vector spaces, eigenvalues and eigenvectors, the state transition matrix and solution of linear differential equations, internal and external system descriptions, properties of controllability and observability and their applications to minimal realizations, state-feedback controllers, asymptotic observers, and compensator design using state-space and transfer function methods. An introduction to multi-input, multi-output systems is also included, as well as the solution and properties of time-varying systems.

**Prerequisites**: Courses in matrix theory and linear differential equations

**Instructor**: Pue

### 525.484 Microwave Systems and Components

This course deals with the practical aspects of microwave systems and components. An overview of radar systems (including the effects of both standoff and escort jamming environments) is followed by an introduction to communication systems. The majority of the course treats the linear and nonlinear characteristics of individual components and their relation to system performance. Amplifiers, mixers, antennas, filters, and frequency sources are studied, as well as their interactions in cascade. Homework problems for each class reinforce the lecture material and may require use of computer-aided design software.

**Prerequisite**: An undergraduate degree in electrical engineering or equivalent.

**Instructors**: Edwards, Kaul, Marks, Wilson

### 525.491 Fundamentals of Photonics

This course provides the essential background in photonics necessary to understand modern photonic and fiber-optic systems. A fundamental background is established, necessary for advanced studies as well. Topics include electromagnetic optics, polarization and crystal optics, guided-wave optics, fiber optics, photons in semiconductors, semiconductors in photon sources and detectors, nonlinear optics, electro-optics, and acousto-optics.

**Prerequisite**: An undergraduate course in electromagnetic theory.

**Instructor**: Sova

### 525.707 Error Control Coding

This course presents error control coding with a view toward applying it as part of the overall design of a data communication or storage and retrieval system. Block, trellis, and turbo codes and associated decoding techniques are covered. Topics include system models, generator and parity check matrix representation of block codes, general decoding principles, cyclic codes, an introduction to abstract algebra and Galois fields, BCH and Reed–Solomon codes, analytical and graphical representation of convolutional codes, performance bounds, examples of good codes, Viterbi decoding, BCJR algorithm, turbo codes, and turbo code decoding.

**Prerequisites**: Background in linear algebra, such as 625.409 Matrix Theory; in probability, such as 525.414 Probability and Stochastic Processes for Engineers; and in digital communications, such as 525.416 Communication Systems Engineering. Familiarity with MATLAB or similar programming capability.

**Instructor**: Hammons

### 525.708 Iterative Methods in Communications Systems

Generalization of the iterative decoding techniques invented for turbo codes has led to the theory of factor graphs as a general model for receiver processing. This course will develop the general theory of factor graphs and explore several of its important applications. Illustrations of the descriptive power of this theory include the development of high-performance decoding algorithms for classical and modern forward error correction codes (trellis codes, parallel concatenated codes, serially concatenated codes, low-density parity check codes). Additional applications include coded modulation systems in which the error correction coding and modulation are deeply intertwined, as well as a new understanding of equalization techniques from the factor graph perspective.

**Prerequisites**: Background in linear algebra, such as 625.409

Matrix Theory; in probability, such as 525.414 Probability and Stochastic Processes for Engineers; and in digital communications, such as 525.416 Communication Systems Engineering. Familiarity with MATLAB or similar programming capability.

**Instructor**: Hammons

### 525.712 Advanced Computer Architecture

This course covers topics essential to modern superscalar processor design. A review of pipelined processor design and hierarchical memory design is followed by advanced topics including the identification of parallelism in processes; multiple diversified functional units in a pipelined processor; static, dynamic, and hybrid branch prediction techniques; the Tomasulo algorithm for efficient resolution of true data dependencies; advanced data flow techniques with and without speculative execution; multiprocessor systems; and multithreaded processors.

**Prerequisite**: 525.412 Computer Architecture or equivalent.

**Instructor**: Faculty

### 525.713 Analog Integrated Circuit Design

This course focuses on CMOS analog integrated circuits. Topics include devices, subthreshold operation, simple amplifiers, reference circuits, and differential amplifiers. Voltage and current mode techniques are introduced for the implementation of analog signal processing. Circuit analysis methodologies are stressed and complemented with design tools for layout, simulation, and verification. A final project involves the design of a small circuit, with the possibility of fabrication through MOSIS.

**Prerequisites**: 525.424 Analog Electronic Circuit Design I or equivalent, and 525.428 Introduction to CMOS VLSI.

**Instructor**: Faculty

### 525.718 Multirate Signal Processing

Multirate signal processing techniques find applications in areas such as communication systems, signal compression, and sub-band signal processing. This course provides an in-depth treatment of both the theoretical and practical aspects of multirate signal processing. The course begins with a review of discrete-time systems and the design of digital filters. Sample rate conversion is covered, and efficient implementations using polyphase filters and cascade integrator comb (CIC) filters are considered. The latter part of the course treats filter bank theory and implementation, including quadrature mirror, conjugate quadrature, discrete Fourier transform, and cosine modulated filter banks along with their relationship to transmultiplexers.

**Prerequisites**: 525.427 Digital Signal Processing or equivalent and working knowledge of MATLAB.

**Instructor**: Younkins

### 525.721 Advanced Digital Signal Processing

The fundamentals of discrete-time statistical signal processing are presented in this course. Topics include estimation theory, optimal linear filter theory, recursive methods for optimal filters, classical and modern spectrum analysis, and adaptive filtering, as well as the singular value decomposition and its applications. Basic concepts of super-resolution methods are described.

**Prerequisites**: 525.414 Probability and Stochastic Processes for Engineers, 525.427 Digital Signal Processing, and the basics of linear algebra; familiarity with a scientific programming language such as MATLAB.

**Instructors**: Najmi, Rodriguez

### 525.722 Wireless and Mobile Cellular Communications

In this course, students examine fundamental concepts of mobile cellular communications and specifics of current and proposed US cellular systems. Topics include frequency reuse; call processing; propagation loss; multipath fading and methods of reducing fades; error correction requirements and techniques; modulation methods; FDMA, TDMA, and CDMA techniques; microcell issues; mobile satellite systems; and IMT-2000.

**Prerequisites**: 525.414 Probability and Stochastic Processes for Engineers or equivalent and 525.416 Communication Systems Engineering.

**Instructor**: Zuelsdorf

### 525.723 Computer and Data Communication Networks II

This course emphasizes the mathematical analysis of communication networks. Queuing theory and its applications are covered extensively, including the topics of M/M/1 systems, M/G/1 systems, Burke's theorem, and Jackson's theorem. Multi-access communication is discussed, including the topics of Aloha systems and packet radio networks. Students also explore network routing including the Bellman–Ford algorithm, Dijkstra's algorithm, and optimal routing.

**Prerequisite**: 525.441 Computer and Data Communication Networks I.

**Instructor**: Hanson

### 525.724 Introduction to Pattern Recognition

This course focuses on the underlying principles of pattern recognition and on the methods of machine intelligence used to develop and deploy pattern recognition applications in the real world. Emphasis is placed on the pattern recognition application development process, which includes problem identification, concept development, algorithm selection, system integration, and test and validation. Machine intelligence algorithms to be presented include feature extraction and selection, parametric and nonparametric pattern detection and classification, clustering, artificial neural networks, support vector machines, rule-based algorithms, fuzzy logic, genetic algorithms, and others. Case studies drawn from actual machine intelligence applications will be used to illustrate how methods such as pattern detection and classification, signal taxonomy, machine vision, anomaly detection, data mining, and data fusion are applied in realistic problem environments. Students will use the MATLAB programming language and the data from these case studies to build and test their own prototype solutions.

**Prerequisites**: 525.414 Probability and Stochastic Processes for Engineers or equivalent. A course in digital signal or image processing is recommended, such as 525.427 Digital Signal Processing, 525.419 Introduction to Digital Image and Video Processing, 525.443 Real-Time Computer Vision, or 525.746 Image Engineering.

**Instructor**: Baumgart

### 525.725 Power Electronics

This course covers the design and analysis of DC-to-DC switching converters. Topics include topology selection for various applications, steady-state operation including continuous versus discontinuous operation, fundamentals of control loop design including both voltage mode and current mode control, fundamentals of magnetic design including how to minimize losses, input and output filter design, pulse-width modulation chip selection, diode and transistor part selection and the associated effects of part non-idealities on the converter performance, and modeling of the converter. The complete process of converter design and implementation is presented including requirement specification and testing verification needed to evaluate the converter performance, such as efficiency, regulation, line rejection, EMI/EMC measurements, and stability measurements. Two labs that will give the student hands-on experience with design and testing of a typical DC-to-DC converter are part of the course.

**Prerequisite**: 525.424 Analog Electronic Circuit Design I or equivalent.

**Instructor**: Katsis

### 525.728 Detection and Estimation Theory

Both hypothesis testing and estimation theory are covered. The course starts with a review of probability distributions, multivariate Gaussians, and the central limit theorem. Hypothesis testing areas include simple and composite hypotheses and binary and multiple hypotheses. In estimation theory, maximum likelihood estimates and Bayes estimates are discussed. Practical problems in radar and communications are used as examples throughout the course.

**Prerequisite**: 525.414 Probability and Stochastic Processes for Engineers or equivalent.

**Instructors**: Banerjee, Marble

### 525.735 MIMO Wireless Communications

This course presents the fundamental concepts and techniques of multiple-input, multiple-output (MIMO) communications over wireless communication channels. MIMO communications, which involve the use of multiple antennas at the transmitter and receiver, employ the use of signal processing techniques to enhance the reliability and capacity of communication systems without increasing the required spectral bandwidth. MIMO techniques are currently used or planned in many commercial and military communications systems. Topics include the derivation and application of the theoretical MIMO communications capacity formula; channel fading and multipath propagation; the concepts of transmit and receive space diversity; space-time block coding, with a special emphasis on Alamouti coding; space-time trellis coding; spatial multiplexing; and fundamentals of OFDM modulation and its relation to MIMO communications. Examples and applications will be presented as well as related MATLAB homework assignments.

**Prerequisites**: 525.416 Communication Systems Engineering; 525.414 Probability and Stochastic Processes for Engineers, or the equivalent. In addition, a working knowledge of MATLAB is required.

**Instructor**: Hampton

### 525.736 Smart Antennas for Wireless Communications

The theory and implementation of smart antennas is explored, including electromagnetic principles, array signal processing, random processes, channel characterization, spectral estimation, and adaptive algorithms. The fundamentals of electromagnetics, antenna elements, antenna arrays, sidelobe cancellation, and adaptive antennas methods will be covered. MATLAB will be used for instruction, simulation, and homework.

**Prerequisites**: 525.414 Probability and Stochastic Processes for Engineers; 525.418 Antenna Systems. Knowledge of MATLAB will be helpful.

**Instructor**: Roddewig

**525.738 Advanced Antenna Systems**

This course is designed to follow 525.418 Antenna Systems. Advanced techniques needed to analyze antenna systems are studied in detail. Fourier transforms are reviewed and applied to antenna theory and array distributions. The method of moments is studied and used to solve basic integral equations employing different basis functions. Green's functions for patch antennas are formulated in terms of Sommerfeld-like integrals. Techniques such as saddle-point integration are presented. Topics addressed include computational electromagnetics, leaky and surface waves, mutual coupling, and Floquet modes. Students should be familiar with complex variables (contour integration), Fourier transforms, and electromagnetics from undergraduate studies.

**Prerequisites**: 525.418 Antenna Systems.

**Instructor**: Weiss

**525.742 System-on-a-Chip FPGA Design Laboratory**

This lab-oriented course will focus on the design of large-scale system-on-a-chip (SOC) solutions within field-programmable gate arrays (FPGAs). Modern FPGA densities and commercially available cores enable a single developer to design highly complex systems within a single FPGA. This class will provide the student with the ability to design and debug these inherently complex systems. Topics will include high-speed digital signal processing, embedded processor architectures, customization of soft-core processors, interfacing with audio and video sensors, communications interfaces, and networking. The optimum division of algorithms between hardware and software will be discussed, particularly the ability to accelerate software algorithms by building custom hardware. Many labs will center around a common architecture that includes signal processing algorithms in the FPGA fabric, controlled by an embedded processor that provides user interfaces and network communication. The first section of the course will be spent experimenting with different building blocks for constructing SOCs. Students will spend later class sessions working in teams on self-directed SOC design projects. Industry-standard tools will be used.

**Prerequisites**: 525.442 FPGA Design Using VHDL and familiarity with C programming.

**Instructors**: Haber, Wenstrand

**525.743 Embedded Systems Development Laboratory**

This project-based laboratory course involves the development of embedded system prototypes. Typical projects contain combinations of the following component types: transducers, analog front ends, micro-controllers and processors, FPGAs, digital signal processors, electrical interfaces, wired or wireless connectivity, printed circuit boards required for integration and test, and software/ firmware modules needed to operate designed system. The laboratory activity is a backdrop used to teach key aspects of the development process such as documentation, realistic use of requirements, design partition, integration strategy, interface design, risk mitigation, and design strategies to accommodate available resources. Students will select a project concept and then create an implementation plan that will define the semester's activity. Students may work independently or in teams to define, develop, test, and document their projects. Students are encouraged to select topics based on their interests and learning objectives. All projects are subject to instructor approval.

**Prerequisites**: An undergraduate degree in electrical or computer engineering or computer science, 525.412 Computer Architecture, and working knowledge of C or C++ or instructor's approval.

**Instructor**: Houser

**525.744 Passive Emitter Geo-Location**

This course covers the algorithms used to locate a stationary RF signal source, such as a radar, radio, or cell phone. The topics covered include a review of vectors, matrices, and probability; linear estimation and Kalman filters; nonlinear estimation and extended Kalman filters; robust estimation; data association; measurement models for direction of arrival, time difference of arrival, and frequency difference of arrival; geo-location algorithms; and performance analysis. Most of the course material is developed in planar Cartesian coordinates for simplicity; however, the extension to WGS84 coordinates is provided to equip the students for practical applications. Homework consists of both analytical problems and problems that require computer simulation using software such as MATLAB.

**Prerequisites**: 525.414 Probability and Stochastic Processes for Engineers, an undergraduate course in linear algebra/matrix theory, and familiarity with MATLAB.

**Instructor**: Grabbe

**525.745 Applied Kalman Filtering**

Theory, analysis, and practical design and implementation of Kalman filters are covered, along with example applications to real-world problems. Topics include a review of random processes and linear system theory; Kalman filter derivations; divergence analysis; numerically robust forms; suboptimal filters and error budget analysis; prediction and smoothing; cascaded, decentralized, and federated filters; linearized, extended, second-order, and adaptive filters; and case studies in GPS, inertial navigation, and ballistic missile tracking.

**Prerequisites**: 525.414 Probability and Stochastic Processes for Engineers and 525.466 Linear System Theory or equivalents; knowledge of MATLAB (or equivalent software package).

**Instructors**: Samsundar, Watkins

### 525.746 Image Engineering 🏛

The overall goal of the course is to provide the student with a unified view of images, concentrating on image creation, and image processing. Optical, photographic, analog, and digital image systems are highlighted. Topics include image input, output, and processing devices; visual perception; video systems; and fundamentals of image enhancement and restoration. Coding, filtering, and transform techniques are covered, with applications to remote sensing and biomedical problems.

**Prerequisites**: 525.427 Digital Signal Processing or equivalent and knowledge of linear systems.

**Instructor**: Miller

### 525.747 Speech Processing 🏛

This course emphasizes processing of the human speech waveform, primarily using digital techniques. Theory of speech production and speech perception as related to signals in time and frequency domains is covered, as well as the measurement of model parameters, short-time Fourier spectrum, and linear predictor coefficients. Speech coding, recognition, and synthesis, as well as speaker identification, are discussed. Application areas include telecommunications telephony, Internet VOIP, and man–machine interfaces. Considerations for embedded realization of the speech processing system will be covered as time permits. Several application-oriented software projects will be required.

**Prerequisites**: 525.427 Digital Signal Processing and 525.414 Probability and Stochastic Processes for Engineers. Background in linear algebra and MATLAB is helpful.

**Instructor**: Carmody

### 525.748 Synthetic Aperture Radar 🏛

This course covers the basics of synthetic aperture radar (SAR). In particular, the course will examine why there are limiting design considerations for real aperture radar and how a synthetic aperture can overcome these limitations to create high-resolution radar imaging. Strip-map and spotlight SAR will be compared and contrasted. Spotlight SAR technology will be compared to computerized axial tomography (CAT). Signal processing of the SAR data will be covered, including motion compensation, Doppler beam-sharpening, polar formatting, aperture weighting (or apodization), and auto-focus. Advanced topics will include interferometric processing of SAR data, a brief overview of bi-static SAR, moving targets in SAR, and the difficulty in estimating motion of targets in single-channel SAR. Students will work through problems involving radar and synthetic aperture radar processing. Over the life of the course, each student will develop a SAR simulator that will generate synthetic data based on simple point scatterers in a benign background. The simulator will include an image formation processor, based on modules built by the student.

**Prerequisites**: 525.448 Introduction to Radar Systems, along with basic MATLAB skills.

**Instructor**: Jansing

### 525.751 Software Radio for Wireless Communications 🏛

This course will explore modern software radio technology and implementation. Digital signal processors and field-programmable gate arrays have traditional uses in radar and digital signal and system processing. However, with advances in design they have started to be employed as key components in software radios. We will explore concepts and techniques that are key to implementing traditionally analog processing functions and ASICs in easily reconfigured digital logic. Students will design software radio functions and algorithms and program FPGA development kits using industry-standard tools and techniques. A semester project involving software GPS radio or other topics is required.

**Prerequisites**: 525.438 Introduction to Wireless Technology or 525.416 Communication Systems Engineering, 525.427 Digital Signal Processing; and working knowledge of MATLAB and Simulink.

**Instructor**: Chew

### 525.753 Laser Systems and Applications 🏛

This course provides a comprehensive treatment of the generation of laser light and its properties and applications. Topics include specific laser systems and pumping mechanisms, nonlinear optics, temporal and spatial coherence, guided beams, interferometric and holographic measurements, and remote sensing.

**Prerequisite**: 525.425 Laser Fundamentals.

**Instructors**: A. Brown, D. Brown, Thomas

### 525.754 Wireless Communication Circuits 🏛

In this course, students examine modulator and demodulator circuits used in communication and radar systems. A combination of lectures and laboratory experiments addresses the analysis, design, fabrication, and test of common circuits.

Signal formats considered include phase and frequency shift keying, pseudo-random codes, and the linear modulations used in analog systems.

**Prerequisite**: 525.416 Communication Systems Engineering or 525.484 Microwave Systems and Components or permission of the instructor.

**Instructors**: Houser, Kaul, K. Lee, Tobin

### 525.756 Optical Propagation, Sensing, and Backgrounds

This course presents a unified perspective on optical propagation in linear media. A basic background is established using electromagnetic theory, spectroscopy, and quantum theory. Properties of the optical field and propagation media (gases, liquids, and solids) are developed, leading to basic expressions describing their interaction. The absorption line strength and shape and Rayleigh scattering are derived and applied to atmospheric transmission, optical window materials, and propagation in water-based liquids. A survey of experimental techniques and apparatus is also part of the course. Applications are presented for each type of medium, emphasizing remote sensing techniques and background noise. Computer codes such as LOWTRAN, FASCODE, and OPTIMATR are discussed.

**Prerequisites**: Undergraduate courses on electromagnetic theory and elementary quantum mechanics. A course on Fourier optics is helpful.

**Instructor**: Thomas

### 525.759 Image Compression, Packet Video, and Video Processing

This course provides an introduction to the basic concepts and techniques used for the compression of digital images and video. Video compression requirements, algorithm components, and ISO-standard video processing algorithms are studied. Image compression components that are used in video compression methods are also identified. Because image and video compression is now integrated in many commercial and experimental video processing methods, knowledge of the compression methods' effects on image and video quality are factors driving the usability of those data in many data exploitation activities. Topics to be covered include introduction to video systems, Fourier analysis of video signals, properties of the human visual system, motion estimation, basic video compression techniques, video-communication standards, and error control in video communications. Video processing applications that rely on compression algorithms are also studied. A mini-project is required.

**Prerequisite**: 525.427 Digital Signal Processing.

**Instructor**: Beser

### 525.761 Wireless and Wireline Network Integration

This course investigates the integration of wireless and wireline networks into seamless networks. The current telecommunications environment in the United States is first discussed, including the state of technology and regulations as they apply to the wireless and wireline hybrid environment. Then each type of these hybrid networks is discussed, including its components, network services, architecture, and possible evolution, as well as important concepts that support the evolution of networks. The integration of wired network advance intelligence, wireless network mobility, and long-distance capabilities are shown to provide many new combinations of wired and wireless services to users.

**Prerequisite**: 525.408 Digital Telephony or 525.416 Communication Systems Engineering, or permission of instructor.

**Instructor**: R. Lee

### 525.762 Signal Processing with Wavelets

This course covers the mathematical framework for wavelets, with particular emphasis on algorithms and implementation of the algorithms. Concepts of frames, orthogonal bases, and reproducing kernel Hilbert spaces are introduced first, followed by an introduction to linear systems for continuous time and discrete time. Next, time, frequency, and scale localizing transforms are introduced, including the windowed Fourier transform and the continuous wavelet transform (CWT). Discretized CWT are studied next in the forms of the Haar and the Shannon orthogonal wavelet systems. General multi-resolution analysis is introduced, and the time domain and frequency domain properties of orthogonal wavelet systems are studied with examples of compact support wavelets. The discrete wavelet transform (DWT) is introduced and implemented. Biorthogonal wavelet systems are also described. Orthogonal wavelet packets are discussed and implemented. Wavelet regularity and the Daubechies construction is presented next. Finally the 2D DWT is discussed and implemented. Applications of wavelet analysis to de-noising and image compression are discussed together with an introduction to image coding.

**Prerequisites**: 525.427 Digital Signal Processing and the basics of linear systems.

**Instructor**: Najmi

### 525.763 Applied Nonlinear Systems

This course provides an introduction to nonlinear systems, including differences between linear and nonlinear systems; mathematical preliminaries; equilibrium points of nonlinear systems; phase plane analysis and limit cycles; stability definitions for nonlinear systems; Lyapunov's indirect and direct methods; stability of autonomous and non-autonomous systems; describing function analysis; nonlinear control design including sliding-mode, adaptive, and nonlinear robust control; and applications of nonlinear control design.

**Prerequisites**: 525.409 Continuous Control Systems or equivalent.

**Instructor**: Ambrose

### 525.768 Wireless Networks 🏛

This is a hands-on course that integrates teaching of concepts in wireless LANs and offers students, in an integrated lab environment, the ability to conduct laboratory experiments and design projects that cover a broad spectrum of issues in wireless LANs. The course will describe the characteristics and operation of contemporary wireless network technologies such as the IEEE 802.11 and 802.11s wireless LANs and Bluetooth wireless PANs. Laboratory experiments and design projects include MANET routing protocols, infrastructure and MANET security, deploying hotspots, and intelligent wireless LANs. The course will also introduce tools and techniques to monitor, measure, and characterize the performance of wireless LANs as well as the use of network simulation tools to model and evaluate the performance of MANETs.

**Prerequisite**: 525.441 Computer and Data Communication Networks I or 605.471 Principles of Data Communications Networks.

**Instructor**: Refaei

### 525.770 Intelligent Algorithms 🏛

Intelligent algorithms are, in many cases, practical alternative techniques for tackling and solving a variety of challenging engineering problems. For example, fuzzy control techniques can be used to construct nonlinear controllers via the use of heuristic information when information of the physical system is limited. Such heuristic information may come, for instance, from an operator who has acted as a "human-in-the-loop" controller for the process. This course investigates a number of concepts and techniques commonly referred to as intelligent algorithms; discusses the underlying theory of these methodologies when appropriate; and takes an engineering perspective and approach to the design, analysis, evaluation, and implementation of intelligent systems. Fuzzy systems, genetic algorithms, particle swarm and ant colony optimization techniques, and neural networks are the primary concepts discussed in this course, and several engineering applications are presented along the way. Expert (rule-based) systems are also discussed within the context of fuzzy systems. An intelligent algorithms research paper must be selected from the existing literature, implemented by the student, and presented as a final project.

**Prerequisite**: Student familiarity of system-theoretic concepts is desirable.

**Instructor**: Palumbo

### 525.771 Propagation of Radio Waves in the Atmosphere 🏛

This course examines various propagation phenomena that influence transmission of radio frequency signals between two locations on Earth and between satellite–Earth terminals, with a focus on applications. Frequencies above 30 MHz are considered, with emphasis on microwave and millimeter propagation. Topics include free space transmission, propagation, and reception; effects on waves traversing the ionosphere; and attenuation due to atmospheric gases, rain, and clouds. Brightness temperature concepts are discussed, and thermal noise introduced into the receiver system from receiver hardware and from atmospheric contributions is examined. Also described are reflection and diffraction effects by land terrain and ocean, multipath propagation, tropospheric refraction, propagation via surface and elevated ducts, scatter from fluctuations of the refractive index, and scattering due to rain. Atmospheric dynamics that contribute to the various types of propagation conditions in the troposphere are described.

**Prerequisite**: An undergraduate degree in electrical engineering or equivalent.

**Instructor**: Dockery

### 525.772 Fiber-Optic Communication Systems 🏛

This course investigates the basic aspects of fiber-optic communication systems. Topics include sources and receivers, optical fibers and their propagation characteristics, and optical fiber systems. The principles of operation and properties of optoelectronic components, as well as the signal guiding characteristics of glass fibers, are discussed. System design issues include terrestrial and submerged point-to-point optical links and fiber-optic networks.

**Prerequisite**: 525.491 Fundamentals of Photonics.

**Instructor**: Sova

### 525.774 RF and Microwave Circuits I 🏛

In this course, students examine RF and microwave circuits appropriate for wireless communications and radar sensing. It emphasizes the theoretical and experimental aspects of micro-strip design of highly integrated systems. Matrix analysis and computer-aided design techniques are introduced and used for the analysis and design of circuits. Circuits are designed, fabricated, and tested, providing a technically stimulating environment in which to understand the foundational principles of circuit development. Couplers, modulators, mixers, and calibrated measurements techniques are also covered.

**Prerequisite**: 525.423 Principles of Microwave Circuits or 525.420 Electromagnetic Transmission Systems.

**Instructors**: Penn, Thompson

### 525.775 RF and Microwave Circuits II

This course builds on the knowledge gained in 525.774 RF and Microwave Circuits I. In this course there is a greater emphasis on designs involving active components. Linear and power amplifiers and oscillators are considered, as well as stability, gain, and their associated design circles. The course uses computer-aided design techniques, and students fabricate and test circuits of their own design.

**Prerequisite**: 525.774 RF and Microwave Circuits I.

**Instructors**: Penn, Thompson

### 525.776 Information Theory

Information theory concerns the fundamental limits for data compressibility and the rate at which data may be reliably communicated over a noisy channel. Course topics include measures of information, entropy, mutual information, Markov chains, source coding theorem, data compression, noisy channel coding theorem, error-correcting codes, and bounds on the performance of communication systems. Classroom discussion and homework assignments will emphasize fundamental concepts, and advanced topics and practical applications (e.g., industry standards, gambling/finance, machine learning) will be explored in group and individual research projects.

**Prerequisite**: 525.414 Probability and Stochastic Processes for Engineers or equivalent.

**Instructor**: Ratto

### 525.777 Control System Design Methods

This course examines recent multi-variable control system design methodologies and how the available techniques are synthesized to produce practical system designs. Both the underlying theories and the use of computational tools are covered. Topics include review of classical control system design and linear system theory, eigen-structure assignment, the linear quadratic regulator, the multi-variable Nyquist criterion, singular value analysis, stability and performance robustness measures, loop transfer recovery, H-infinity design, and mu-synthesis. An introduction to nonlinear techniques includes sliding mode control and feedback linearization. Recent papers from the literature are discussed. Each student will be assigned a design project using PC-based design and analysis software.

**Prerequisites**: 525.466 Linear System Theory and 525.409 Continuous Control Systems or the equivalent.

**Instructor**: Pue

### 525.778 Design for Reliability, Testability, and Quality Assurance

The design of reliable and testable systems, both analog and digital, is considered at the component, circuit, system, and network levels. Using numerous real-world examples, the trade-offs between redundancy, testability, complexity, and fault tolerance are explored. Although the emphasis is predominantly on electronics, related examples from the aerospace and software industries are included. The concepts of fault lists, collapsed fault lists, and other techniques for reducing the complexity of fault simulation are addressed. A quantitative relationship between information theory, error correction codes, and reliability is developed. Finally, the elements of a practical quality assurance system are presented. In addition to homework assignment, students will conduct an in-depth, quantitative case study of a practical system of personal interest.

**Instructor**: Jablonski

### 525.779 RF Integrated Circuits

This course covers the RFIC design process focusing on the RF/ microwave portion of RFIC. An overview of digital circuits and digital signal processing will be given along with semiconductor fabrication, device models, and RF/microwave design techniques using a typical SiGe process. Part of the course will involve student design projects using Analog Office software to design amplifiers, mixers, etc.

**Prerequisite**: 525.774 RF and Microwave Circuits I or equivalent.

**Instructors**: Penn, Wilson

### 525.780 Multidimensional Digital Signal Processing

The fundamental concepts of multidimensional digital signal processing theory as well as several associated application areas are covered in this course. The course begins with an investigation of continuous-space signals and sampling theory in two or more dimensions. The multidimensional discrete Fourier transform is defined, and methods for its efficient calculation are discussed. The design and implementation of two-dimensional non-recursive linear filters are treated. The final part of the course examines the processing of signals carried by propagating waves. This section contains descriptions of computed tomography and related techniques and array signal processing. Several application-oriented software projects are required.

**Prerequisites**: 525.414 Probability and Stochastic Processes for

Engineers and 525.427 Digital Signal Processing or equivalents. Knowledge of linear algebra and MATLAB is helpful.

**Instructor**: Newsome

### 525.783 Spread-Spectrum Communications

This course presents an analysis of the performance and design of spread-spectrum communication systems. Both direct-sequence and frequency-hopping systems are studied. Topics include pseudonoise sequences, code synchronization, interference suppression, and the application of error-correcting codes. The use of code-division multiple access in digital cellular systems is examined. The relationships between spread spectrum, cryptographic, and error correction systems are explored. The mathematics of pseudo-random sequences used as spreading codes is compared with the mathematics of complex numbers with which students are already familiar.

**Prerequisites**: 525.416 Communication Systems Engineering. Students should have knowledge of material covered in 525.201 Circuits, Devices, and Fields and 525.202 Signals and Systems.

**Instructor**: Jablonski

### 525.786 Human Robotics Interaction

This course provides an investigation of human–robot interaction and prosthetic control, with a focus on advanced man–machine interfaces including neural signal processing, electromyography, and motion tracking interfaces for controlling and receiving feedback from robotic devices. The course will also cover human physiology and anatomy, signal processing, intent determination, communications between the human and the device, haptic feedback, and telepresence. It is designed to be a hands-on course with class time spent in the dedicated robotics lab designing interfaces and performing experiments in a virtual integration environment (VIE) and with robotic devices. Additional time in the lab, outside of class time, may be required to complete the course project. Programming for the class will be in MATLAB and Simulink.

**Prerequisites**: 525.427 Digital Signal Processing, knowledge of linear algebra, and familiarity with MATLAB and Simulink.

**Instructors**: Armiger, Lesho

### 525.787 Microwave Monolithic Integrated Circuit (MMIC) Design

This course is for advanced students who have a background in microwave circuit analysis and design techniques and are familiar with modern microwave computer-aided engineering tools. The course covers the monolithic implementation of microwave circuits on Gams. As substrates including instruction on processing, masks, simulation, layout, design rule checking, packaging, and testing. The first part of the course includes information and assignments on the analysis and design of MMIC chips. The second part consists of projects in which a chip is designed, reviewed, and evaluated in an engineering environment, resulting in a chip mask set that is submitted for foundry fabrication.

**Prerequisite**: 525.775 RF and Microwave Circuits II.

**Instructor**: Penn

### 525.788 Power Microwave Monolithic Integrated Circuit (MMIC) Design

This course covers additional circuit design techniques applicable to MMICs (and microwave circuits in general). It is an extension of 525.774/775 RF and Microwave Circuits I and II and 525.787 Microwave Monolithic Integrated Circuit (MMIC) Design, although for students with a microwave background, these particular courses are not prerequisites. The topics covered include broadband matching, optimum loads for efficiency and low intermodulation products, odd mode oscillations, details of nonlinear modeling, time domain simulation of nonlinear circuits, and thermal effects. Students do need to have a background in microwave measurements and microwave CAD tools. No project is required, but there is structured homework involving power MMIC design completed by the student using a foundry library.

**Instructor**: Dawson

### 525.789 Digital Satellite Communications

This course covers advanced topics in satellite communications systems, with emphasis on digital communications. After a review of basic concepts, the following topics are addressed: the distinctions between digital and nondigital communications systems; reasons for preferring some forms of modulation and coding over others for spacecraft implementation; the relationships between spectrum management, signal propagation characteristics, orbitology, constellation design, and communications system design; the use of spread spectrum (CDMA and frequency-hopping), TDMA, and FDMA architectures; protocol design and usage; GPS; digital audio radio satellites; the use of geostationary satellites for mobile telephone systems; satellite television; and VSAT terminals.

**Prerequisites**: 525.416 Communication Systems Engineering is required, and 525.440 Satellite Communications Systems is recommended. Students should have knowledge of material covered in 525.201 Circuits, Devices, and Fields and 525.202 Signals and Systems.

**Instructor**: Jablonski

**525.791 Microwave Communications Laboratory**

Concepts involving the design and fabrication of microwave subsystems are introduced in this laboratory course, including image rejection mixers, local oscillators, phase locked loops, and microstrip filters. A communication project is required, such as design and fabrication of an L-band WEFAX (weather facsimile) receiver or a C-band AMSAT (amateur communications satellite) converter. Modern microwave analyzing instruments are used by the students to evaluate the performance of the project subsystems.

**Prerequisite**: 525.774 RF and Microwave Circuits I.

**Instructors**: Everett, Fazi

**525.792 Electro-Optical Systems**

This course covers the analysis and conceptual design of practical electro-optical (EO) systems. Although EO technology is emphasized, the fundamentals of radiometry and optical radiation are also described to provide an understanding of the essential physics, whereas background characterization and atmospheric propagation are only briefly covered. Basic EO system component performance is characterized parametrically for detection, tracking, communications, and imaging. Passive (infrared imaging) and active (laser radar and laser communication systems) are stressed. Components considered in these systems include basic telescopes and optics, focal plane arrays, laser diodes, photodiode receivers, and laser scanners.

**Prerequisite**: 615.751 Modern Optics or the equivalent.

**Instructors**: Boone, Edwards

**525.793 Advanced Communication Systems**

This course provides a basic introduction to the various building blocks of a modern digital communications system, focusing on the physical layer (PHY). We will first review basic concepts in digital communications, including Shannon theory, Nyquist sampling theory, optimal detection under Gaussian white noise, and basic modulations. We will then treat several building blocks of a digital receiver, including time and frequency synchronization, adaptive equalization and precoding, and error-correction coding/ decoding. We will also introduce some advanced communication technologies such as orthogonal frequency-division multiplexing (OFDM) and multiple-input, multiple-output (MIMO). Finally we will apply the knowledge to some practical wireless and wired systems.

**Prerequisites**: 525.414 Probability and Stochastic Processes for Engineers; 525.416 Communication Systems Engineering.

**Instructor**: Ouyang

**525.796 Introduction to High-Speed Electronics and Optoelectronics**

This course provides the student with the fundamental concepts needed to address issues in both the design and test of high-speed electronic and optical systems. Topics include electronic devices and circuits used at microwave and millimeter frequencies, optical active devices and waveguide technology, electronic and optical pulse generation techniques, high-speed packaging design, and testing techniques.

**Prerequisites**: Undergraduate courses in circuits and systems.

**Instructor**: Sova

**525.797 Advanced Fiber Optic Laboratory**

The purpose of this laboratory course is to expose students to state-of-the-art applications of fiber optic technologies that include continuous-wave (cw) and pulsed fiber lasers, high-speed digital fiber optic communication systems, microwave photonic links, and non-linear fiber optic signal processing and sensors. The first part of the course will focus on a thorough characterization of fiber laser systems starting with the erbium-doped fiber amplifier and implementing different laser configurations that include multi-mode cw operation, Q-switching and relaxation oscillations, non-linear based mode-locking and single longitudinal mode operation. All of the measurements will be compared to theoretical models. This will provide students with hands-on experience to concepts that are applicable to all laser systems. In the latter part of the course, students will select a few topics that demonstrate both modern fiber optic systems based on cw lasers, external electro-optic modulators and high-speed photodetectors and applications of nonlinear fiber optics using self-phase modulation, stimulated Brillouin scattering, stimulate Raman scattering and four wave mixing. These topics highlight the breath of applications of modern fiber optic systems. Again, all of the experiments will be compared to theoretical models.

**Prerequisite**: 525.491 Fundamentals of Photonics or 615.751 Modern Optics or equivalent.

**Instructor**: Sova

**525.801 Special Project I**

In individual cases, special arrangements can be made to carry out a project of significant scope in lieu of a formal course. Further information is available from the program chair. Such arrangements are made relatively infrequently. This course number should be used for the first registration of a student in any special project.

**Course Note**: To be assured consideration for any term, project proposals should reach the program chair by the end of the registration period.

**Instructor**: Faculty

### 525.802 Special Project II 🏛

This course number should be used for the second registration of a student in any special project. (See course 525.801 Special Project I for a further description.)

**Course Note**: To be assured consideration for any term, project proposals should reach the program chair by the end of the registration period.

**Instructor**: Faculty

### 525.803 Electrical and Computer Engineering Thesis 🏛

First of two-course sequence designed for students in the Electrical And Computer Engineering (ECE) graduate program who wish to undertake a thesis project after completing all other requirements for their degree. Students work with an advisor to conduct independent research and development in ECE, leading to a written thesis and oral presentation to a thesis committee. The intent of the research may be to advance the body of knowledge in one of the technology areas in the ECE program.

**Prerequisites**: Completion of all other courses applicable to the ECE graduate degree and approval of the ECE program chair and vice chair. The thesis option is appropriate for highly motivated students with strong academic records.

**Course Notes**: Students accepted into this course will have off-hours access to ECE facilities at the Applied Physics Laboratory and the Dorsey Center. A limited amount of support for research materials is available.

**Instructor**: Faculty

### 525.804 Electrical and Computer Engineering Thesis 🏛

Second of two-course sequence designed for students in the Electrical And Computer Engineering (ECE) graduate program who wish to undertake a thesis project after completing all other requirements for their degree. Students work with an advisor to conduct independent research and development in ECE, leading to a written thesis and oral presentation to a thesis committee. The intent of the research may be to advance the body of knowledge in one of the technology areas in the ECE program.

**Prerequisites**: Completion of all other courses applicable to the ECE graduate degree and approval of the ECE program chair and vice chair. The thesis option is appropriate for highly motivated students with strong academic records.

**Course Notes**: Students accepted into this course will have off-hours access to ECE facilities at the Applied Physics Laboratory and the Dorsey Center. A limited amount of support for research materials is available.

**Instructor**: Faculty

## MECHANICAL ENGINEERING

### 535.406 Advanced Strength of Materials 🏛

This course reviews stress and strain in three dimensions, elastic and inelastic material behavior, and energy methods. It also covers use of the strength of materials approach to solving advanced problems of torsion, bending of beams and plates, buckling of columns, stress concentrations, and fracture mechanics. The use of finite element analysis in solving problems in mechanics will be introduced as well.

**Course Note**: Required course for Solids track.

**Instructor**: Burkhardt

**Offered**: Fall

### 535.409 Topics in Data Analysis 🏛

This course will provide a survey of standard techniques for the extraction of information from data generated experimentally and computationally. The approach will emphasize the theoretical foundation for each topic followed by applications of each technique to sample experimental data. The student will be provided with implementations to gain experience with each tool to allow the student to then quickly adapt to other implementations found in common data analysis packages. Topics include uncertainty analysis, data fitting, feed-forward neural networks, probability density functions, correlation functions, Fourier analysis and FFT procedures, spectral analysis, digital filtering, and Hilbert transforms.

**Prerequisite**: Projects will require some programming experience or familiarity with tools such as MATLAB.

**Instructor**: Hess

### 535.410 Computational Methods of Analysis 🏛

This course serves as an introduction to using MATLAB for typical engineering analyses and may serve as a valuable precursor to the more computationally intensive courses in the program that use MATLAB. Course topics include an introduction to script programming, solution of one- and two-dimensional definite integrals, solution of coupled sets of ordinary differential equations, typical data analysis (e.g., Fourier transforms, curve fitting, and signal processing), and matrix manipulation (e.g., solution of linear systems and eigenvalue extraction).

**Instructor**: Burkhardt

### 535.411 Structural Dynamics and Stability 🏛

This course introduces the propagation of elastic waves and the loss of stability in engineering structures and systems. In the first part of the course, fundamental physical principles of elasticity and wave mechanics are reviewed and developed to provide students with the capability to model and analyze wave propagation, reflection, and refraction in isotropic and anisotropic engineering structures such as rods, beams, and plates. In the second part of the course, mechanical stability models are studied and applied in terms of dynamic behavior where the combined effects of vibration, gyroscopic motion, impact/shock, and buckling lead to new structural configurations or unstable motions that must often be avoided in design. Applications span nondestructive evaluation, composites, cables, aircraft/space structures, rotordynamics, aeroelasticity, civil engineering structures, and others

**Instructor**: Stanton

### 535.412 Intermediate Dynamics

This course develops students' ability to accurately model the dynamics of single and multi-body engineering systems undergoing motion in 3D space. The course begins with formulating the differential geometry and kinematics of curvilinear coordinates to permit kinematic descriptions of relative motion and rotation of rigid bodies and mechanisms subject to common engineering constraints such as substructure interconnections, dry friction, and rolling. Momentum and inertia properties of rigid body dynamics follow. Students are then introduced to analytical dynamics, where Lagrange's equations and Kane's method are derived and studied to facilitate efficient formulation of the equations of motion governing the dynamics of systems subject to conservative and non-conservative forces and engineering constraints. The course also concludes with gyroscopic dynamics with applications to inertial guidance and spacecraft attitude dynamics.

**Instructor**: Stanton

### 535.414 Fundamentals of Acoustics

This course provides an introduction to the physical principles of acoustics and their application. Fundamental topics include the generation, transmission, and reception of acoustic waves. Applications covered are selected from underwater acoustics, architectural acoustics, remote sensing, and nondestructive testing.

**Prerequisites**: Some familiarity with linear algebra, complex variables, and differential equations.

**Instructor**: Burkhardt

### 535.421 Intermediate Fluid Dynamics

This course prepares the student to solve practical engineering flow problems and concentrates on the kinematics and dynamics of viscous fluid flows. Topics include the control volume and differential formulations of the conservation laws, including the Navier–Stokes equations. Students examine vorticity and circulation, dynamic similarity, and laminar and turbulent flows. The student is exposed to analytical techniques and experimental methods, and the course includes an introduction to computational methods in fluid dynamics. It also includes a programming project to develop a numerical solution to a practical fluid flow problem.

**Prerequisite**: An undergraduate fluid mechanics course.

**Course Note**: Required course for Thermofluids track.

**Instructor**: Hess

**Offered**: Fall

### 535.422 Robot Motion Planning

This course investigates the motion planning problem in robotics. Topics include motion of rigid object by the configurations space and retraction approaches, shortest path motion, motion of linked robot arms, compliant motion, coordinated motion of several objects, robust motion with error detection and recovery, and motion in an unknown environment.

**Instructor**: Kutzer

### 535.423 Intermediate Vibrations

Course topics include transient and forced vibration of one and N-degree of freedom systems and an introduction to vibration of continuous systems. Hamilton's Principle and Lagrange's equations are used throughout the course to derive the equation(s) of motion. MATLAB is introduced and used to solve the equations of motion and plot the response of the system. This course also addresses common topics in applied vibrations such as the environmental testing, the shock response spectrum, random vibration, vibration isolation, and the design of tuned-mass damper systems.

**Prerequisite**: An undergraduate vibrations course.

**Course Note**: Required course for Solids track.

**Instructor**: Stanton

**Offered**: Spring

### 535.424 Energy Engineering

The course will focus on an analytical system performance technique known as "availability or exergy analysis," which is based on the second law of thermodynamics. The course focuses on traditional power and refrigeration systems. However, nontraditional power generation systems will be considered by way of a special project of each student's choice. It will include an engineering description of the state of the art of the selected topic (e.g., wind or solar power, fuel cell, etc.), and a second law performance analysis of a prototype system will be presented to the class. In addition to the power system topics, the availability analysis will be applied to the combustion and psychrometric processes.

**Instructor**: Faculty

### 535.426 Kinematics and Dynamics of Robots
This course introduces the basic concepts and tools used to analyze the kinematics and dynamics of robot manipulators. Topics include kinematic representations and transformations, positional and differential kinematics, singularity and workspace analysis, inverse and forward dynamics techniques, and trajectory planning and control.

**Course Note**: Required course for Robotics and Controls focus area.

**Instructor**: Armand

**Offered**: Fall

### 535.427 Computer-Aided Design
This course provides a wide-ranging exploration of computer-aided design (CAD) using Creo Parametric (a PTC CAD software, previously called Pro/ENGINEER). Topics include sketching, solid modeling, assembly modeling, detail drafting, geometric dimensioning and tolerancing, advanced modeling, sheet metal modeling, mechanism dynamics, and structural/thermal finite element analysis (FEA).

**Instructor**: Boyle

### 535.428 Computer-Integrated Design and Manufacturing
This course emphasizes the computer automation of design and manufacturing systems. A survey of the automation techniques used in modern design and manufacturing facilities is presented. Discussions are presented related to the system integration of computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM), robotics, material resource planning, tool management, information management, process control, and quality control. The current capabilities, applications, limitations, trends, and economic considerations are stressed.

**Course Note**: Required course for Manufacturing focus area.

**Instructor**: Ivester

**Offered**: Spring

### 535.431 Introduction to Finite Element Methods
Topics covered by this course include theory and implementation of finite element models for typical linear problems in continuum mechanics including fluid flow, heat transfer, and solid mechanics. Emphasis will be placed on developing a fundamental understanding of the method and its application.

**Course Note**: Cannot be counted with 560.730 Finite Element Methods.

**Instructor**: Lear

### 535.432 Applied Finite Elements
This course provides an introduction to the study of mechanics using the finite element method. Topics include the stiffness method, stationary principles, the Rayleigh–Ritz method, displacement-based elements, isoparametric formulation, and coordinate transformation. A general-purpose finite element analysis package will be used for computer project assignments. Students who successfully complete this course will be able to utilize general-purpose commercial code to solve linear two- and three-dimensional problems in statics and vibrations.

**Instructor**: Faculty

### 535.433 Intermediate Heat Transfer
This course covers the following topics: transient heat conduction, forced and free convection in external and internal flows, and radiation processes and properties.

**Prerequisite**: An undergraduate heat transfer course.

**Course Note**: Required course for Thermofluids track.

**Instructor**: Green

**Offered**: Spring

### 535.434 Applied Heat Transfer
This course focuses on the inevitable trade-offs associated with any thermodynamic or heat transfer system, which result in a clear distinction between workable and optimal systems. The point is illustrated by means of a number of concrete problems arising in power and refrigeration systems, electronics cooling, distillations columns, heat exchange, and co-generation systems.

**Prerequisite**: An undergraduate heat transfer course.

**Instructor**: Healy

### 535.441 Mathematical Methods for Engineers
This course covers a broad spectrum of mathematical techniques needed to solve advanced problems in engineering. Topics include linear algebra, the Laplace transform, ordinary differential equations, special functions, partial differential equations, and complex variables. Application of these topics to the solutions of physics and engineering problems is stressed.

**Prerequisite**: Vector analysis and ordinary differential equations.

**Instructor**: Nakos

### 535.442 Control Systems for Mechanical Engineering Applications
This class provides a comprehensive introduction to the theory and application of classical control techniques for the design and analysis of continuous-time control systems for mechanical

engineering applications. Topics include development of dynamic models for mechanical, electrical, fluid-flow, and process-control systems; and introduction to Laplace transforms, stability analysis, time and frequency domain analysis techniques, and classical design methods. The class will use a series of applications that build in complexity throughout the semester to emphasize and reinforce the material.

**Course Note**: Required course for Robotics and Controls focus area.

**Instructor**: Urban

**Offered**: Spring

### 535.445 Digital Control and Systems Applications

This class will provide a comprehensive treatment of the analysis and design of discrete-time control systems. The course will build on the student's knowledge of classical control theory and extend that knowledge to the discrete-time domain. This course is highly relevant to aspiring control systems and robotics engineers since most control system designs are implemented in microprocessors (hence the discrete-time domain) vice analog circuitry. Additionally, the course will go into advanced control system designs in the state-space domain and will include discussions of modern control design techniques including linear-quadratic optimal control design, pole-placement design, and state-space observer design. The class will use a series of applications that build in complexity throughout the semester to emphasize and reinforce the material.

**Prerequisite**: 535.442 Control Systems for Mechanical Engineering Applications.

**Instructor**: Urban

### 535.450 Combustion

This is a multidisciplinary course involving applications of thermodynamics, fluid mechanics, heat transfer, and chemistry. Course contents include a review of chemical thermodynamics, chemical kinetics, transport theory, and conservation equations; laminar flow in premixed and non-premixed gases; combustion waves; ignition; combustion aerodynamics; multiphase combustion; and turbulent combustion. Selected applications are discussed including gas turbines, spark ignition and diesel engines, jet engines, industrial furnaces, pollutant formation, and control in combustion.

**Prerequisites**: Undergraduate-level exposure to thermodynamics, fluid dynamics, differential equations, and basic chemistry.

**Instructor**: Kweon

### 535.452 Thermal Systems Design and Analysis

Thermodynamics, fluid mechanics, and heat transfer principles are applied using a systems perspective to enable students to analyze and understand how interactions between components of piping, power, refrigeration, and thermal management systems affect the performance of the entire system. Following an overview of the fundamental principles involved in thermal and systems analyses, the course will cover mathematical methods needed to analyze the systems and will then explore optimization approaches that can be used to improve designs and operations of the thermal systems to minimize, for example, energy consumption or operating costs.

**Prerequisite**: Undergraduate courses in thermodynamics and heat transfer. No computer programming is required.

**Instructor**: Healy

### 535.454 Theory and Applications of Structural Analysis

This is a course in classical plate and shell structures, with an emphasis on both analysis and application. Both differential and energy method approaches are presented. Topics include an introduction to thin plate theory and its application to circular and rectangular plates, as well as buckling and thermal effects. Classical thin shell theory is also presented. Applications to common plate and shell structures are discussed throughout.

**Instructor**: Burkhardt

### 535.458 Design for Manufacturability

The key principles for designing a quality, cost-efficient product are related to competitiveness in manufacturing environments in this course. Topics include design for manufacturing, design for assembly, process selection, inspection planning, concurrent engineering, product re-engineering, quality management, and agile manufacturing. The focus is on engineering designs and system approaches that affect cost, quality, cycle time, and maintainability.

**Instructor**: Ivester

### 535.459 Manufacturing Systems Analysis

This course is a review of the fundamentals of modern manufacturing processes, computer-aided design/manufacturing tools, flexible manufacturing systems, and robots. The course addresses relationships between process machinery, process conditions, and material properties. Examples of high-tech industries illustrate how mechanical and electronic components are manufactured from metals, polymers, ceramics, composites, and silicon.

**Course Note**: Required course for Manufacturing focus area.

**Instructor**: Ivester

**Offered**: Fall

**535.460 Precision Mechanical Design** 🏛

This course will provide the student with a fundamental understanding of the principles and techniques used to design precision machines, instruments, and mechanisms. Lectures will include discussions on the implementation and design of mechanisms, bearings, actuators, sensors, structures, and precision mounts used in precision design. Upon completion of this course, students will have a clear understanding of positional repeatability and accuracy, deterministic design, exact constraint design, error modeling, and sources of machine and instrumentation errors.

**Instructor**: Fesperman

**535.461 Energy and the Environment** 🏛

The course focuses on advanced topics related to energy and thermodynamics. The objective of this course is to provide a thorough understanding of the environmental impacts related to energy conversion systems. The use of the second law of thermodynamics is introduced to quantify the performance of energy conversion systems. Topics such as global warming, alternative energy sources (solar, wind power, geothermal, tides, etc.), new technologies (fuel cells and hydrogen economy), and resources and sustainable development are addressed. A section of the course is devoted to current trends in nuclear energy generation and associated environmental issues.

**Prerequisite**: Undergraduate-level exposure to thermodynamics.

**Instructor**: Herman

**535.472 Advanced Manufacturing Systems** 🏛

This course examines the effect that new technology, engineering, and business strategies have on transforming US industry into a world-class, competitive force. Emphasis is placed on the state of the art of factory automation and computer-integrated manufacturing. Topics include advanced manufacturing processes, rapid prototyping, intelligent manufacturing controls, and information technology in manufacturing. Technical principles related to advanced manufacturing are presented. Examples of actual production systems (including video presentations and plant visits) illustrate how industry is adopting the latest technology to meet customer requirements for quality, low cost, and flexibility.

**Instructor**: Ivester

**535.484 Modern Polymeric Materials** 🏛

This course will cover a broad range of topics in the polymeric materials science and engineering field. We will address the structure and property relationships in thermoplastics, thermoset, amorphous, semicrystalline, oriented and biological polymeric materials; synthesis and processing (including rheology) of polymers; and flow and fracture of polymeric materials under different conditions. Modern polymer characterization techniques will be introduced. Frontiers in the recent findings in biopolymers, polymer-based 3D printing, and polymers for tissue engineering will also be discussed.

**Instructor**: Xia

**535.626 Advanced Machine Design** 🏛

This course provides a broad treatment of stress, strain, and strength with reference to engineering design and analysis. Major emphasis is placed on the analytical and experimental methods of determination of stresses in relationship to the strength properties of machine elements under various loading conditions. Also considered are deflection, post-yield behavior, residual stresses, thermal stresses, creep, and extreme temperature effects as applied to the design of fasteners, shafts, power trains, and rotational machinery.

**Instructor**: Fesperman

**535.636 Applied Computational Fluid Mechanics** 🏛

This course explores engineering applications of computational fluid dynamics with background information on the most common numerical methods: two-dimensional inviscid and viscous flows, boundary layer flows, and an introduction to three-dimensional flows. Applications are illustrated using commercially available codes.

**Prerequisites**: 535.421 Intermediate Fluid Dynamics and 535.441 Mathematical Methods for Engineers. Some programming experience is also assumed.

**Instructor**: Faculty

**535.712 Applied Fluid Dynamics** 🏛

This course will provide a survey of topics in applied fluid dynamics for the practicing engineer. The first topic will concentrate on pipe and duct flow, looking at friction factors, abrupt changes in area, and pipe systems. This is followed by unsteady flows focusing on pressure transients, such as the water hammer. A section on lubrication theory covering wedge and journal bearings is presented. Open channel flows are discussed, with emphasis on optimum cross-sectional shape and specific energy. Turbomachinery such as axial and centrifugal pumps, including specific speed and suction limitations, is described. Fluid dynamic drag and lift from streamlined surfaces are presented, including topics such as vortex shedding, terminal velocity, and cavitation. The approach will emphasize the practical foundation needed to solve real-world problems.

**Prerequisite**: 535.421 Intermediate Fluid Dynamics. Projects will require some programming experience or familiarity with tools such as MATLAB.

**Instructor**: Hess

**535.720 Analysis and Design of Composite Structures**

Topics in this course include anisotropic elasticity, laminate analysis, strength of laminates, failure theories, bending, buckling, and vibration of composite plates. The second part of the course is devoted to the applications of the structural analysis of composite structures by means of finite-elements computer codes.

**Instructor**: Faculty

**535.726 Robot Control**

This course focuses on the theory and methods used for the control of robotic manipulators. Topics include review of basic systems theory, robot position control, model-based trajectory tracking, and force control. Stability properties for each control strategy will be analyzed. Practical implementation issues will also be addressed. Students will simulate different control methods using MATLAB.

**Prerequisites**: 535.426 Kinematics and Dynamics of Robots, ordinary differential equations, linear algebra.

**Instructor**: Armand

**535.731 Engineering Materials: Properties and Selection**

Become familiar with different classes of engineering materials and their trade-offs associated with design criteria such as strength, toughness, corrosion resistance, and fabricability, as well as some common test methods for evaluating material properties. This course will concentrate on metal alloys but will also consider polymers and ceramics. Topics specific to metals will include effects of work hardening and heat treatment, corrosion, and elevated temperature properties. Topics specific to polymers will include viscoelasticity, stress relaxation and creep, and phase transitions. Topics specific to ceramics will include flaw-dominated strength, fracture energy, and statistical determination of strength. The course also includes an introduction to the Ashby method of material selection and optimization.

**Instructor**: Lennon

**Offered**: Spring

## CHEMICAL AND BIOMOLECULAR ENGINEERING

**545.203 Engineering Thermodynamics**

This course covers the formulation and solution of material, energy, and entropy balances, with an emphasis on open systems. A systematic problem-solving approach is developed for chemical process-related systems. This approach consists of decoupling the process into its components, establishing relationships between the known and unknown variables, assembling the information needed to solve for the unknown variables, and then obtaining a physically meaningful solution. Extensive use is made of classical thermodynamic relationships and constitutive equations. Applications include the analysis and design of engines, refrigerators, heat pumps, compressors, and turbines.

**Prerequisites**: 030.101 Introductory Chemistry, 171.101 General Physics for Physical Science Majors I, and either 540.202 Introduction to Chemical & Biological Process Analysis or permission of instructor.

**Corequisite**: 110.202 Calculus III (Calculus of Several Variables).

**Course Note**: Not for graduate credit

**Instructor**: Frechette

**545.204 Applied Physical Chemistry**

This course offers an introduction to the methods used to solve phase and chemical equilibria problems. The basic thermodynamic relationships to describe phase equilibrium of single-component and multicomponent systems are developed. Thermodynamic models for calculating fugacity are presented. These include equations of state, liquid solution models, and fugacity estimation methods. Multicomponent phase equilibrium problems addressed are cover liquid-vapor, liquid-liquid, liquid-liquid-vapor, and solid-vapor. Basic thermodynamic relationships to describe chemical equilibria are also developed and the thermodynamic models for calculating fugacity are applied to their solution.

**Prerequisites**: 540.203 Engineering Thermodynamics and either 540.202 Introduction to Chemical & Biological Process Analysis or permission of instructor.

**Course Note**: Not for graduate credit.

**Instructor**: Gracias

**545.301 Kinetic Processes**

This course provides a review of numerical methods in reactor design, including homogeneous kinetics and interpretation of reaction rate data; batch, plug flow, and stirred tank reactor analyses, including CSTRs in series; selectivity and optimization considerations in multiple reaction systems; non-isothermal reactors; elements of heterogeneous kinetics, including adsorption isotherms and basic Hougen–Watson rate models; coupled transport and chemical reaction rates; and fixed bed reactor design, including axial dispersion models. A brief introduction to residence time distributions and non-ideal reactor models is also provided.

**Prerequisites**: 540.203 Engineering Thermodynamics and 540.303 Transport Phenomena I, and either 540.202 Introduction to Chemical & Biological Process Analysis or permission of instructor.

**Course Note**: Not for graduate credit.

**Instructors**: Cui, Goffin

### 545.303 Transport Phenomena I 🏛

This course provides an introduction to the field of transport phenomena, including molecular mechanisms of momentum transport (viscous flow); energy transport (heat conduction); mass transport (diffusion); isothermal equations of change (continuity, motion, and energy); the development of the Navier Stokes equation; the development of non-isothermal and multicomponent equations of change for heat and mass transfer; and exact solutions to steady-state, isothermal unidirectional flow problems and to steady-state heat and mass transfer problems. The analogies between heat, mass, and momentum transfer are emphasized throughout the course.

**Prerequisites**: A grade of C or better in Calculus I, II, and III and 540.202 Introduction to Chemical & Biological Process Analysis or permission of instructor.

**Corequisite**: 500.303 Applied Mathematics I.

**Course Note**: Not for graduate credit.

**Instructors**: Konstantopoulos, Prakash

### 545.304 Transport Phenomena II 🏛

Topics covered in this course include dimensional analysis and dimensionless groups, laminar boundary layers, introduction to turbulent flow, definition of the friction factor, macroscopic mass, momentum and mechanical energy balances (Bernoulli's equation), metering of fluids, convective heat and mass transfer, heat and mass transfer in boundary layers, correlations for convective heat and mass transfer, boiling and condensation, and interphase mass transfer.

**Prerequisites**: 540.303 Transport Phenomena I and either 540.202 Introduction to Chemical & Biological Process Analysis or permission of instructor.

**Course Note**: Not for graduate credit.

**Instructor**: Drazer

### 545.602 Metabolic Systems Biotechnology 🏛

This course covers molecular biology techniques, including DNA, RNA, and proteins; control of gene expression; microarray technology and proteomics; cell–cell signaling and communication; cell adhesion; extracellular matrix; introductory glycobiology; cell structure, including membrane, cytoskeleton, organelles, proteins secretion and degradation; cell replication and death, including cell cycle, cell division, senescence, and apoptosis; multicellular systems, including fertilization; tissue development, including nervous system, ectoderm (neuronal crest), mesoderm, endoderm metamorphosis, regeneration, and aging; and stem cell biology, including adult and fetal stem cells, germ and embryonic stem cells, cell expansion of undifferentiated and progenitor cells, differentiation regulation, and control/engineering of stem cell renewal and differentiation in vitro.

**Instructors**: Betenbaugh, Konstantopoulos

### 545.603 Colloids and Nanoparticles 🏛

This course explains the fundamental principles related to interactions, dynamics, and structure in colloidal, nanoparticle, and interfacial systems. Concepts covered include hydrodynamics, Brownian motion, diffusion, sedimentation, electrophoresis, colloidal and surface forces, polymeric forces, aggregation, deposition, and experimental methods. Modern topics related to colloids in nano-science and technology will be discussed throughout the course with frequent references to recent literature.

**Instructor**: Bevan

### 545.614 Computational Protein Structure Prediction and Design 🏛

The prediction of protein structure from the amino acid sequence has been a grand challenge for more than fifty years. With recent progress in research, it is now possible to blindly predict many protein structures and even to design new structures from scratch. This class will introduce the fundamental concepts in protein structure, biophysics, optimization, and informatics that have enabled the breakthroughs in computational structure prediction and design. Problems covered will include protein folding and docking, design of ligand-binding sites, design of turns and folds, and design of protein interfaces. Classes will consist of lectures and hands-on computer workshops. Students will learn to use molecular visualization tools and write programs with the PyRosetta protein structure software suite, including a computational project.

**Course Note**: Programming experience is helpful but not required.

**Instructor**: Gray

### 545.615 Interfacial Science with Applications to Nanoscale Systems 🏛

Nanostructured materials intrinsically possess large surface area (interface area) to volume ratios. It is this large interfacial area that gives rise to many of the amazing properties and technologies associated with nanotechnology. In this class, we will examine how the properties of surfaces, interfaces, and nanoscale features differ from their macroscopic behavior. We will compare and contrast fluid–fluid interfaces with solid–fluid and solid–solid interfaces, discussing fundamental interfacial physics and chemistry, as well as touching on state-of-the-art technologies.

**Instructor**: Frechette

### 545.619 Project in Design: Alternative Energy

This design project is focused on the role alternative energy will play in our country's future. About a third of the course will be devoted to understanding the role of energy and alternative energy in the US and world economies. The remainder of the course will be devoted to a technical and economic analysis of the feasibility of making biofuel from algae. Graduate level. Meets with EN.540.401 Projects in Design: Alternative Energy

**Instructor**: Faculty

### 545.621 Project in Design: Pharmacodynamics

This course covers pharmacodynamics, i.e. how pharmaceuticals affect biological processes. The course will use MatLab to aid in the design of new drug formulations.

**Instructor**: Faculty

### 545.622 Introduction to Polymeric Materials

Polymeric materials are ubiquitous in our society from nature made proteins and polysaccharides to synthetic plastics and fibers. Their applications range from day-to-day consumables to high-performance materials used in critically demanding areas, such as aviation, aerospace, and medical devices. The objective of this course is to provide an introductory overview on the field of polymer science and engineering. Students will learn some basic concepts in polymer synthesis, characterization, and processing. With the basic concepts established, industrial applications of polymeric materials will be discussed in two categories: structural polymers and functional polymers. Structural polymers, including plastics, fibers, rubbers, coatings, adhesives, and composites, will be discussed in terms of their structure, processing, and property relationship with a flavor of industrial relevant products and applications. Future trends in developing environmentally friendly polymers from renewable resources (green polymer chemistry) will also be covered. Lectures on functional polymers will focus on their unique properties that are enabled by rational molecular design, controlled synthesis, and processing (e.g., supramolecular assembly and microfabrication). This class of specialty materials can find their use in high-performance photovoltaics, batteries, membranes, and composites and can also serve as smart materials for use in coatings, sensors, medical devices, and biomimicry.

**Instructor**: Faculty

### 545.628 Supramolecular Materials and Nanomedicine

Nanomedicine is a quickly growing area that exploits the novel chemical, physical, and biological properties of nanostructures and nanostructured materials for medical treatments. This course presents basic design principles of constructing nanomaterials for use in drug delivery, disease diagnosis and imaging, and tissue engineering. Three major topics will be discussed, including 1) nanocarriers for drug delivery that are formed through soft matter assembly (e.g., surfactants, lipids, block copolymers, DNA, polyelectrolytes, peptides), 2) inorganic nanostructures for disease diagnosis and imaging (e.g., nanoparticles of gold and silver, quantum dots and carbon nanotubes), and 3) supramolecular scaffolds for tissue engineering and regenerative medicine. Students are expected to learn the physical, chemical and biological properties of each nanomaterial, the underlying physics and chemistry of fabricating such material, as well as their advantages and potential issues when used for biomedical applications. This course will also provide students opportunities for case studies on commercialized nanomedicine products. After this class, students should gain a deeper understanding of current challenges in translating nanoscience and nanotechnology into medical therapies.

**Instructor**: Faculty

### 545.630 Thermodynamics and Statistical Mechanics

In this course we will aim for understanding the thermodynamics of chemical and bio-molecular systems. We will first review classical, macroscopic thermodynamics covering concepts such as equilibrium, stability and the role of thermodynamic potentials. Our goal will be to gain a feel for the generality of thermodynamics. Statistical mechanics provides a link between the mechanics of atoms and macroscopic thermodynamics. We will introduce this branch in two distinct ways: 1) following standard methods of developing concepts such as ensembles and partition functions, and 2) where we will treat the basis of statistical mechanics as a problem in inference. With this foundation, we will consider concepts relevant to understanding the liquid state. Chemical transformations in a liquid are of importance in much of chemistry and biology; quasi-chemical generalizations of the potential distribution theorem will be introduced to present these ideas. We hope to give an overview of modern developments relating equilibrium work to non-equilibrium work, as these are of increasing importance in studies on single molecule systems. Registration by instructor permission only.

**Instructor**: Faculty

**545.637 Molecular Evolution of Biotechnology**

One of the most promising strategies for successfully designing complex biomolecular functions is to exploit nature's principles of evolution. This course provides an overview of the basics of molecular evolution as well as its experimental implementation. Current research problems in evolution-based biomolecular engineering will be used to illustrate principles in the design of biomolecules (i.e., protein engineering, RNA/DNA engineering), genetic circuits, and complex biological systems including cells.

**Instructor**: Ostermeier

**545.640 Micro and Nanotechnology**

The field of micro / nanotechnology has been gaining tremendous momentum as evidenced by an explosive rise in the number of publications, patents and commercial activities. This is an introductory course intended to expose students to the field as well as real world applications. Lectures will include an overview of scaling of material properties at the nanoscale, micro and nanofabrication methods and essential analytical tools of relevance to the field. All through the course, we will go over electronic, optical and biological applications of emerging micro and nanoscale devices and materials.

**Instructor**: Faculty

**545.643 Chemical Reaction Engineering**

The principles of chemical reaction engineering will be illustrated through practical applications in sufficient rigor to facilitate comprehensive understanding of the subject. Application of reaction engineering principles in a variety of industries such as petrochemicals, specialty chemicals and pharmaceuticals will be presented. For example, students will learn about the basics of reaction kinetics, heterogeneous catalysis, the effect of transfer limitations and turbulent mixing on product distribution and yield and scale-up principles in fermenters. Mastery of these principles will allow for generalizations and should prepare the student for the needs of the chemical industry that has expanded from its historic petrochemicals focus.

**Instructor**: Faculty

**545.652 Fundamentals of Transport Phenomena**

This lecture course introduces students to the application of engineering fundamentals from transport and kinetic processes to vascular biology and medicine. The first half of the course addresses the derivation of the governing equations for Newtonian fluids and their solution in the creeping flow limit. The second half of the course considers how these concepts can be used to understand the behavior of a deformable cell near planar surfaces.

**Prerequisite**: Undergraduate Transport Phenomena is preferred.

**Instructor**: Faculty

**545.661 Nanobioengineering Laboratory**

Students explore different experimental methodologies in Nanobioengineering. Students work in small teams to complete one or more major projects expanding their understanding and applying their theoretical knowledge to practical problems. The course will employ a variety of experimental methods, from material synthesis to biological applications. Students report several times either orally and in writing on their accomplishments. Project meetings may be held outside of the appointed class time.

**Instructor**: Faculty

**545.662 Design Projects in Nanobioengineering**

In this course, students will design/optimize a process or product in the field of Nanobioengineering. Students will choose a project from a list of suggested topics and complete their design in small groups. Students will have an introductory session to develop a deeper understanding of their project and afterwards will meet weekly with faculty members to discuss their progress. Project meetings will be scheduled based upon the availability of the students and faculty member(s).

**Instructor**: Faculty

**545.672 Green Engineering, Alternative Energy and CO2 Capture/Sequestration**

This course inherently combines green engineering, alternative energy and CO2 capture and storage into a concentrated semester lecture.

Green Engineering applies the cost-effective design, commercialization, and use of chemical processes in ways that minimize pollution at the source, and reduce impact on human activities and the environment. After general discussion of applying environmental principles into various chemical processes, this course will switch the gear to apply these green engineering ideas into the energy production that has increasing and critical importance to our modern world, how to minimize the pollution and CO2 emission. There are two ways to follow:

1. Alternative Energy, which uses alternative resources rather than the current dominant fossil fuel for energy production. Alternative energy includes solar, hydro, bioenergy, geothermal, tidal, nuclear energy and et al. The detailed production processes, the long term perspective, policy and advantages/disadvantages over their counterpart, fossil fuel, will be discussed.
2. Fossil fuel with CO2 Capture and Storage. CO2 capture methods such as chemical solvents/chemical looping, membrane, oxy fuel combustion will be discussed and their technical benefits/limitations will be studied. The storage

will cover geological methods (coal bed and saline aquifer), enhanced oil recovery, ocean storage, terrestrial and others. The technical details, cost, future trends and national/international policy (carbon taxes/markets) will be discussed in this course.

**Instructor**: Wang

# CIVIL ENGINEERING

### 565.410 In Situ and Laboratory Testing Methods for Soil Construction

The course covers selection of field and laboratory testing of soils based on site conditions, project specificities, and expected soil response to project loads. In situ field testing includes standard penetration test, cone penetrometer test, pressuremeter, dilatometer, and vane shear. Laboratory tests of soil include soil characterization, direct shear, triaxial compression (static and cyclic), consolidation, and advanced testing. The course covers development of a geotechnical investigation plan, including field exploration and laboratory testing to support the design and analysis of soil constructions. In situ geotechnical monitoring instrumentation, data acquisition, and management are covered.

**Prerequisites**: 560.305 Soil Mechanics or equivalent.

**Instructor**: de Melo

**Offered**: Occasionally

### 565.415 Applied Finite Element Methods

This course will introduce finite element methods for the analysis of solids and structures. The following topics will be considered: procedure for defining a mechanics problem (governing equations, constitutive equations, boundary and initial value problems); theory and implementation of the finite element method for static analysis using linear elasticity; and the verification/validation of results using finite element analysis software.

**Course Note**: This course is a requirement for the Structural Engineering focus area.

**Instructor**: Ucak

### 565.429 Preservation Engineering

This course will examine structures made using materials that are no longer in widespread use (e.g. unreinforced masonry arches and vaults, cast iron, and wrought iron) as well as structural materials for which analysis and design practices have changed significantly over the last half-century (e.g. wood, steel, and reinforced concrete), and it will instruct the student how to evaluate their condition, determine their existing capacity, and design repairs and/or reinforcement. Site visits near Homewood campus will supplement lectures.

**Instructors**: Meade, Spivey

### 565.430 Design of Wood Structures

This course introduces students to the design of wood structures. Wood structures may be constructed of sawn lumber, glulam, or engineered wood products. The primary focus in this class is on light-framed low-rise wood buildings constructed of sawn lumber or glulam, but concepts related to heavy timber-framed structures and tall wood buildings using cross-laminated timber (CLT) are introduced. Structural behavior under gravity and lateral loads is emphasized, as is analysis and design of the components within the gravity and lateral load resisting systems. The current version of the National Design Specification (NDS) for Wood Construction is used.

**Instructor**: Sangree

### 565.450 Introduction to Construction Management

An introduction to the "business side" of construction projects. Topics include an evaluation of delivery systems used in construction projects (fixed price, cost plus, design-build, design-bid-build, etc.), CPM scheduling, techniques for resolving job site conflicts and schedule delays, and Building Information Management (BIM).

**Instructor**: Schied

### 565.460 Catastrophe Modeling: An Engineer's Guide to Disaster Risk Management

An Introduction to the elements of the theory and practice of disaster risk management (DRM). This class will provide hands-on experience in quantitative modeling of risk with an open catastrophe modeling tool, enable attendants as risk practitioners to query the right questions and interpret complex results, highlight differences in modeling approaches (aggregated v. site specific analyses), decide among diverse risk estimates of the same phenomenon, and estimate project costs associated with disasters.

**Instructor**: Pita

### 565.475 Advanced Soil Mechanics

This course discusses the difference between soils and other materials; stresses in soils due to structural foundations; elastic, consolidation, and secondary consolidation settlements of footings; shear strength and stress-strain behavior of clays and sands; approximate nonlinear elastic, Mohr–Coulomb, Ramberg–Osgood, and hyperbolic stress-strain models for soils; nonlinear Winkler foundation analysis of piles, pile groups, and drilled shafts due to vertical and horizontal loads; and foundation spring constraints for superstructure analysis.

**Prerequisite**: 560.305 Soil Mechanics or equivalent.

**Course Note**: This course is a requirement for the Geotechnical Engineering focus area.

**Instructor**: Jadi

### 565.480 Earth Engineering 🏛

This course primarily deals with design and construction methods of Earth embankments, as well as concepts related to soil as construction material. Covered topics include subsurface exploration techniques, soil classification methods, stress distribution theories, elastic and consolidation settlement analysis, cut and fill embankment construction, groundwater and seepage, compaction theory, and embankment slope stability. Case histories of embankment on soft ground will be discussed, with introduction to advanced topics such as staged construction, physical and chemical soil stabilization, and pile supported embankments. Discussions on testing of embankment during construction and performance monitoring with geotechnical instrumentation will be provided.

**Prerequisite**: 560.305 Soil Mechanics or equivalent

**Course Note**: This course is a requirement for the Geotechnical Engineering focus area.

**Instructor**: Kesavan

### 565.600 Structural Mechanics 🔀

This course presents basic solid mechanics for structural engineers, including stress, strain, and constitutive laws; linear elasticity and visco-elasticity; introduction to nonlinear mechanics; static, dynamic, and thermal stresses; specialization of theory to one- and two-dimensional cases; plane stress and plane strain, rods, and beams; work and energy principles; and variational formulations.

**Course Note**: This course is a requirement for the Structural Engineering focus area.

**Instructor**: Harris

### 565.605 Advanced Reinforced Concrete Design 🔀

This intensive course covers reinforced concrete materials and specifications and includes the following topics: conception, analysis, and design of continuous beams and frames; building; bridges and shells; elements theory, with emphasis on the ultimate strength method; precast and prestressed concrete; and special topics.

**Prerequisite**: 560.325 Concrete Structures or equivalent.

**Instructor**: Dutta, Wolski

### 565.620 Advanced Steel Design 🔀

This course examines advanced designs of structural steel building, including consideration of torsion, lateral-torsional buckling, plastic design, plate girders, framing systems for seismic design, and principles of stability including the direct analysis method.

**Prerequisite**: 560.320 Steel Structures or equivalent.

**Instructors**: Wheaton

### 565.625 Advanced Foundation Design 🏛

The course covers performance requirements and review of soil mechanics, laboratory testing, and the latest subsurface investigation and in situ testing methods as they relate to foundation design; bearing capacity and settlements of shallow foundations; design and construction of rammed aggregate piers; design and construction of driven and drilled deep foundations; axial and lateral capacity and settlement of deep foundations; dynamic analysis and evaluation by wave equation and dynamic testing methods; axial load tests and interpretation; and pile integrity testing.

**Prerequisites**: 565.475 Advanced Soil Mechanics.

**Instructor**: Tucker

### 565.629 Preservation Engineering in the Urban Context 🏛

Technical expertise is fundamental to design and construction within and around historic buildings in the urban context. This course will cover topics related to both design and construction. For below-grade engineering, the course will cover underpinning, bracket piles, secant piles, slurry walls, tie-backs and general shoring approaches to building below or adjacent to existing constructions. For upward additions to existing construction, the course covers strengthening techniques (including temporary shoring and bracing, temporary access options, and temporary protection) and the requirements of the International Existing Building Code (IEBC). Each class will provide both technical guides and case studies, offering perspectives from guest speakers practicing the diverse range of professions tasked to meet this challenge.

**Instructors**: Matteo, Spivey

### 565.630 Prestressed Concrete Design 🏛

Topics include prestressed concrete materials, prestressing systems, and loss of prestress; analysis and design of sections for flexure, shear, torsion, and compression; and consideration of partial prestress, composite sections, and slabs.

**Prerequisites**: 560.325 Concrete Structures or equivalent.

**Instructor**: Hayek

### 565.635 Ground Improvement Methods 🏛

This course addresses the selection, cost, design, construction, and monitoring of ground improvement methods for problematic soils and rock. Ground improvement methods covered include wick drains, micropiles, lightweight fill materials, soil nailing, mechanically stabilized slopes and walls, grouting, stone columns, dynamic compaction, and soil mixing.

**Prerequisites**: 560.330 Foundation Design or equivalent and 565.475 Advanced Soil Mechanics.

**Instructor**: Chen

**565.640 Instrumentation in Structural and Geotechnical Engineering**

This course introduces concepts, technologies, procedures, and applications of instrumentation in structural and geotechnical engineering. The structural applications include bridge load rating, fatigue evaluation, connection/bearing performance, and problem diagnosis. The geotechnical applications include in situ determination of soil and rock properties and performance monitoring of soil and foundation elements. Geotechnical instrumentation details will include design phase, construction phase, and post-construction phase applications.

**Instructors**: Kesavan, Zhou

**Offered**: Occasionally

**565.645 Marine Geotechnical Engineering**

This course introduces students to soil mechanics in the marine environment. Topics covered include the nature of marine sediments, soil behavior due to cyclic loading, marine geotechnical investigations, shallow foundations and dead-weight anchors, pile foundations and anchors, penetration and breakout of objects on the seafloor, marine slope stability, soft ground improvement, marine dredging, and project planning.

**Prerequisites**: 560.305 Soil Mechanics or equivalent.

**Instructor**: Mouring

**565.650 Port and Harbor Engineering**

Planning and engineering of ports and harbors has received renewed worldwide interest as the newest super-large cargo ships push the envelope for channel depth and berth space. This course covers planning of marine terminals and small-craft harbors, ship berthing and maneuvering considerations, port navigation, marine structures, inland navigation, marine construction planning, sediment management, and port economics. A field trip to the Port of Baltimore provides practical application of course material and shows students firsthand the unique challenges of engineering on the waterfront.

**Instructor**: Mouring

**565.660 Design of Ocean Structures**

This course emphasizes methods for adapting to coastal hazards such as hurricanes, tsunamis, and sea level rise. Topics include surf zone and nearshore processes, equilibrium beaches, beach nourishment, living shorelines and sills, bio¬engineering approaches, use of vegetation and vegetated buffers, and use of sand dunes and berms. Other topics include FEMA provisions for sustainable residential and building construction, hurricane-resistant construction, and flood-proofing.

**Instructor**: Mouring

**565.671 Sustainable Coastal Engineering**

This course emphasizes methods for adapting to coastal hazards such as hurricanes, tsunamis, and sea level rise. Topics include surf zone and nearshore processes, equilibrium beaches, beach nourishment, living shorelines and sills, bio¬engineering approaches, use of vegetation and vegetated buffers, and use of sand dunes and berms. Other topics include FEMA provisions for sustainable residential and building construction, hurricane-resistant construction, and flood-proofing.

**Instructor**: Mouring

**565.715 Application of Numerical Methods in Geotechnical Engineering**

This course presents a review of different numerical methods and their applicability and limitations to analysis and design in geotechnical engineering. The course includes an overview of finite differences, boundary elements, and the finite element method (FEM) for stress-strain analysis of soil constructions and limit equilibrium methods for slope stability analysis. Also included are applications of FEM and slope stability software to analysis and design in geotechnical engineering.

**Instructor**: de Melo

**Offered**: Occasionally

**565.742 Soil Dynamics and Geotechnical Earthquake Engineering**

This course provides a study of soil behavior under dynamic loading conditions, including wave propagation and attenuation, field and laboratory techniques for determining dynamic soil properties and cyclic strength, cyclic stress strain behavior of soils, liquefaction and evaluation of liquefaction susceptibility, nondestructive evaluation of foundation systems, and foundation design for vibratory loadings.

**Prerequisites**: 560.305 Soil Mechanics or equivalent.

**Instructor**: Faculty

**Offered**: Occasionally

**565.745 Retaining Structures and Slope Stability**

Topics for this course include Earth pressure theories; design and behavior of rigid, flexible, braced, tied-back, slurry, and reinforced soil structures; stability of excavation, cut, and natural slopes; methods of slope stability analysis; effects of water forces; shear strength selection for analysis; and stability and seepage in embankment dams.

**Prerequisites**: 560.305 Soil Mechanics or equivalent.

**Instructor**: Chen

**565.752 Structural Dynamics**
This course provides a brief review of rigid-body dynamics, Lagrange's equations and Hamilton's principle, free and deterministic forced vibration of undamped and damped single- and multi-degree of freedom systems, vibration of continuous systems, approximate methods of analysis, and introduction to random vibration of linear systems.
**Instructor**: Yeo
**Offered**: Occasionally

**565.756 Earthquake Engineering I**
Topics for this course include plate tectonics, seismicity of Earth, and engineering seismology—including quantification and classification of earthquake ground motions, dynamics of structures subjected to earthquake loads, design spectra, building code provisions, design concepts and detailing, soil-structure interaction, and response of special structures.
**Instructor**: Harris

**565.758 Wind Engineering**
This course covers atmospheric circulation, atmospheric boundary layer winds, bluff-body aerodynamics, modeling of wind-induced loads, introduction to random vibration theory, response of structures to fluctuating wind loads, aeroelastic phenomena, wind-tunnel and full-scale testing, nonsynoptic winds (hurricanes, tornadoes, etc.), and wind-load standards and design applications.
**Instructor**: Simiu, Yeo

**565.784 Bridge Design and Evaluation**
This course covers design of new bridges and evaluation of existing bridges in accordance with current AASHTO specifications. The procedures and requirements of bridge design and evaluation will be discussed, and the corresponding AASHTO code provisions will be explained through examples. Main topics include overview and history of bridge engineering, bridge design and evaluation methods and procedures, bridge superstructure design, bridge substructure design, fatigue and fracture of steel bridges, bridge load rating, advanced methods and technologies for bridge condition assessment, as well as case studies.
**Instructor**: Zhou

**565.800 Independent Study in Civil Engineering**
Permission of instructor required.
**Instructor**: Faculty

**565.801 Independent Study in Civil Engineering**
Permission of instructor required.
**Instructor**: Faculty

## ENVIRONMENTAL ENGINEERING, SCIENCE, AND MANAGEMENT

**575.401 Fluid Mechanics**
This course introduces the principles of continuity, momentum, and energy applied to fluid motion. Topics include hydrostatics; ideal-fluid flow; laminar flow; turbulent flow; form and surface resistance with applications to fluid measurement; and flow in conduits and channels, pumps, and turbines.
**Instructor**: Haq
**Offered**: Spring

**575.404 Principles of Environmental Engineering**
This course addresses the wide range of environmental engineering fundamentals with quantitative analyses where applicable. Topics include mass and energy transfer and balances; environmental chemistry; mathematics of growth and decay; risk assessment and management; surface water pollutants, biological and chemical oxygen demands; eutrophication; water supply systems and drinking water standards; wastewater treatment systems and effluent standards; groundwater flow, contaminant transport, and remediation technologies; hazardous waste and pollution prevention; remedial and corrective actions at contaminated sites; air pollution sources, control technologies, and atmospheric stability; ambient air quality standards and indoor air quality; global temperature, greenhouse effect, and warming potential; global energy balance, carbon emission, and stratospheric ozone depletion; solid waste management, landfill disposal, combustion, composting, and recycling; medical waste; and environmental law, ethics, and justice. Field trips are integrated into the classes.
**Prerequisites**: This course is required of all degree students studying environmental engineering, science, and management
who do not possess an undergraduate degree in environmental engineering.
**Instructors**: Alavi, Kim, Overcash
**Offered**: Fall, Spring, Summer

**575.405 Principles of Water and Wastewater Treatment**
Water quality objectives and the chemical, physical, and biological processes necessary for designing and managing modern drinking water and wastewater treatment plants are described in the course. The principles of coagulation, flocculation, sedimentation, filtration, biological treatment, solids handling, disinfection, and advanced treatment processes are presented. The course serves as a basis for the more

advanced courses: 575.745 Physical and Chemical Processes for Water and Wastewater Treatment, 575.706 Biological Processes for Water and Wastewater Treatment, and 575.746 Water and Wastewater Treatment Plant Design.

**Prerequisites**: 575.401 Fluid Mechanics or an equivalent course in fluid flow or hydraulics, two semesters of undergraduate chemistry.

**Instructors**: Davies-Venn, Movahed

**Offered**: Spring

### 575.406 Water Supply and Wastewater Collection

This course covers the design of reservoirs, conduits, water distribution systems, well fields, sewers, and drains. Included is a study of population growth and its effects on water supply requirements and sewage flows as well as techniques for analyzing rainfall, runoff, fluid flow, reservoir siting, and groundwater flows.

**Prerequisite**: 575.403 Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

**Instructors**: Davies-Venn, Shin

**Offered**: Fall

### 575.407 Radioactive Waste Management

This course covers fundamental aspects of radioactive substances in the environment; remediation processes for these substances; and their eventual storage, processing, and disposal. It provides a basic understanding of radioactivity and its effect on humans and their environment, as well as the techniques for their remediation and disposal. Topics include radioactivity, the nucleoids, interaction of radiation with matter, shielding, dosimetry, biological effects, protection standards, sources of environmental radiation, risk evaluation, fate and transport analysis, cleanup standards, legal requirements, cleanup technologies, waste disposal, as well as case studies.

**Instructor**: Lightner

**Offered**: Fall

### 575.408 Optimization Methods for Public Decision Making

This course is an introduction to operations research as applied in the public sector. Public-sector operations research involves the development and application of quantitative models and methods intended to help decision makers solve complex environmental and socioeconomic problems. The course material is motivated by real-world problems and is presented in an environmental engineering-relevant context. Such problems include air pollution control, water resources management, transportation planning, scheduling, resource allocation, facility location, and biological conservation. Emphasis is placed on skill development in the definition of problems, the formulation of models, and the application of solution methodologies. Methodologies covered in this course include linear programming, integer programming, multi-objective optimization, and dynamic programming.

**Instructor**: Williams

**Offered**: Summer

### 575.411 Economic Foundations for Public Decision Making

The course examines intermediate-level price theory and surveys applications to public-sector decision making. Topics include demand, supply, behavior of the market, and introductory welfare economics. Applications include forecasting, benefit-cost analysis, engineering economics, and public sector pricing.

**Instructor**: Boland

**Offered**: Spring

### 575.415 Ecology

Course topics include an introduction to the organization of individual organisms into populations, communities, and ecosystems; interactions between individual organisms, groups of organisms, and the environment (including competition, natural selection, adaptation, diversity, and the role of climate change on migration and extinction); the effect of acidification of the environment (including deforestation); and other human impacts on species diversity, community structure, and ecosystem stability.

**Instructor**: Hillgartner

**Offered**: Fall

### 575.416 Engineering Risk and Decision Analysis

This course introduces students to the methods of risk analysis and decision analysis for engineers. Both quantitative and qualitative risk analysis methods will be covered. Topics will include qualitative risk analysis methods (risk lists; matrices; failure modes and effects analysis; failure modes, effects, criticality analysis, etc.), quantitative engineering risk analysis methods (fault trees, event trees, etc.), environmental health risk analysis methods, decision bases, the axioms underlying decision analysis, and quantitative decision analysis methods (decision trees, utility functions, risk attitude, value of information calculations, etc.). The course also covers risk perception, risk communication, and risk governance. Expert assessment and the role of cognitive biases in the expert assessment process are included as well. The focus of this course is on the fundamentals of risk and decision analysis rather than their application in a particular field. Examples will be provided on a variety of different fields of engineering, including space system design, environmental management, nuclear stockpile reliability, groundwater cleanup, and electric power system reliability assessment.

**Instructor**: Guikema

**Offered**: Fall

### 575.419 Principles of Toxicology, Risk Assessment, and Management

Risk assessment and risk management have become central tools in continued efforts to improve public safety and the environment within the limited resources available. This course introduces the basic concepts of environmental risk assessment, relative risk analysis, and risk perception, including identifying and quantifying human health impacts and evaluating ecological risk. The course describes legislative and regulatory initiatives that are attempting to base decisions on risk assessment, along with the controversy that surrounds such approaches. It also addresses specific federal requirements for risk analysis by industry. The course discusses the realities of using risk assessments in risk management decisions, including the need to balance costs and benefits of risk reduction, issues of environmental equity, accounting for the uncertainties in risk estimates, effective risk communication, and acceptable risk.

**Instructor**: Dellarco

**Offered**: Fall

### 575.420 Solid Waste Engineering and Management

This course covers engineering and scientific concepts and principles applied to the management of municipal solid waste (MSW) to protect human health and the environment and the conservation of limited resources through resource recovery and recycling of waste material. Topics include regulatory aspects and hierarchy of integrated solid waste management; characterization and properties of MSW; municipal wastewater sludge utilization; hazardous waste found in MSW; collection, transfer, and transport of solid waste; separation, processing, combustion, composting, and recycling of waste material; and the landfill method of solid waste disposal, which encompasses guidelines for design, construction, operation, siting, monitoring, remedial actions, and closure of landfills. Permitting and public participation processes, current issues, and innovative approaches are also addressed.

**Instructors**: Alavi, Kim, Overcash

**Offered**: Fall

### 575.423 Industrial Processes and Pollution Prevention

This course presents the pollution prevention and waste minimization concepts, terminologies, life cycle impacts, and management strategies. The course introduces available remediation techniques for industrial pollution control and prevention and examines specific applications to industries including biological, chemical, physical, and thermal techniques. Topics include the current state of knowledge of pollution prevention approaches to encourage pollution prevention strategies, highlights of selected clean technologies and clean products, technical and economic issues, incentives and barriers to pollution prevention, and the role of different sectors in promoting pollution prevention. Pollution prevention and waste minimization techniques such as waste reduction, chemical substitution, production process modification, and reuse and recycling will be addressed with regard to selected industries such as textiles, electroplating, pulp and paper, and petroleum refining.

**Instructor**: Engel-Cox

**Offered**: Fall

### 575.426 Hydrogeology

This course is an introduction to groundwater and geology and the interactions between the two. It provides a basic understanding of geologic concepts and processes, focusing on understanding the formation and characteristics of water-bearing formations. The course also addresses the theory of groundwater flow, the hydrology of aquifers, well hydraulics, groundwater-resource evaluation, and groundwater chemistry. The relationship between the geologic concepts/processes and the groundwater resource is discussed. Examples include a discussion of the influence of the geologic environment on the availability and movement of groundwater and on the fate and transport of groundwater contaminants. Geotechnical engineering problems associated with groundwater issues are also covered.

**Instructor**: Barranco, Root

**Offered**: Fall

### 575.428 Business Law for Engineers

This course introduces engineers to the basic legal principles they will encounter throughout their careers. Course discussions cover contracts (formation, performance, breach, and termination), corporations and partnerships, insurance, professional liability, risk management, environmental law, torts, property law, and evidence and dispute resolution. The course emphasizes those principles necessary to provide engineers with the ability to recognize issues that are likely to arise in the engineering profession and introduces them to the complexities and vagaries of the legal profession.

**Instructor**: Alavi-Hantman

**Offered**: Fall

### 575.429 Modeling Contaminant Migration Through Multimedia Systems

This course addresses contamination that can affect many media as it migrates through the environment. Typically, contaminant sources occur in soil, from which the chemicals then migrate to air, surface water, and groundwater. Predicting the movement of contaminants through these media requires addressing the fate and transport processes that predominate in each medium and integrating the interactions between the media. The course presents the basic principles and numerical methods for simulation contaminant migration from soil into and through surface-water bodies, air, and groundwater. The basic processes of fate and transport in the various media will be addressed: entrainment, adsorption, volatilization, chemical reactions such as degradation and photolysis, convection, and Gaussian dispersion and deposition. Selected public-domain numerical models will be used to simulate the fate and transport processes. Central to the course will be a project that integrates multimedia environmental modeling through a case study.

**Instructors**: Robert, Root, Stoddard

**Offered**: Summer

### 575.435 Environmental Law for Engineers and Scientists

This course explores fundamental legal concepts relevant to environmental issues, including the relationship between statutes, regulations, and court decisions. Also included are various forms of enforcement used in environmental rules: command and control, liability, and information disclosure. Specific issues include criminal enforcement, a survey of environmental statutes, regulations and case law, the purpose and misconceptions surrounding environmental audits and assessments, the concept of attorney–client privilege, unauthorized practice of law, and ethical conflicts between the attorney and engineer/scientist roles.

**Instructors**: Gorski, Henderson

**Offered**: Fall

### 575.437 Environmental Impact Assessment

This course examines principles, procedures, methods, and applications of environmental impact assessment. The goal of the course is to promote an understanding of how environmental impact assessment is conducted and used as a valuable tool in the engineering project management decision-making process. Topics include an overview of environmental impact assessment; selection of scientific, engineering, and socioeconomic factors in environmental impact assessment; identification of quantitative and qualitative environmental evaluation criteria; application of traditional and other techniques for assessing impacts of predicted changes in environmental quality; approaches for identifying, measuring, predicting, and mitigating environmental impacts; modeling techniques employed in environmental impact assessment; environmental standards and the environmental impact assessment process; and methodologies for incorporating environmental impact assessment into management decision making. Students learn to prepare an environmental impact assessment, review and critically analyze an environmental impact statement, use mathematical models for environmental impact prediction, and apply environmental impact assessment as a tool in management decision making. Case studies of environmental impact assessment for several types of engineering projects are employed.

**Instructor**: Toussaint

**Offered**: Spring

### 575.440 Geographic Information Systems (GIS) and Remote Sensing for Environmental Applications

Through lectures and laboratory exercises, this course illustrates the fundamental concepts of GIS and remote sensing technologies in the context of environmental engineering. Topics include the physical basis for remote sensing, remote sensing systems, digital image processing, data structures, database design, and spatial data analysis. The course is not intended to provide students with extensive training in particular image processing or GIS packages. However, hands-on computer laboratory sessions reinforce critical concepts. Completion of a term project is required.

**Prerequisite**: Working knowledge of personal computers

**Instructor**: Roper

**Offered**: Spring

### 575.443 Aquatic Chemistry

Thermodynamics and equilibrium are applied to processes in natural waters, water supply systems, wastewater treatment systems, and other water-based systems. Topics include the chemistry of electrolyte solutions, acids and bases, dissolved carbonate and other pH-buffering solutes, the precipitation and dissolution of inorganic solids, complex formation and chelation, and oxidationreduction reactions. Quantitative problem solving and the visualization of chemical speciation are emphasized.

**Instructor**: Gilbert

**Offered**: Summer

### 575.445 Environmental Microbiology

This course covers fundamental aspects of microbial physiology and microbial ecology. Specific areas of focus include energetics and yield, enzyme and growth kinetics, cell structure and physiology, metabolic and genetic regulation, microbial/environmental interactions, and biogeochemical cycles. The goal of this course is to provide a basic understanding and appreciation of microbial processes that may be applicable to environmental biotechnology.

**Instructor**: Wadhawan

**Offered**: Summer

### 575.703 Environmental Biotechnology

This course examines current applications of biotechnology to environmental quality evaluation, monitoring, and remediation of contaminated environments. The scale of technology ranges from the molecular to macrobiotic. Relevant topics of microbiology and plant biology are presented. These provide a foundation for subsequent discussions of microbial removal and degradation of organics, phytoremediation of soil and water contaminated with toxic metals and radionuclides, wetlands as treatment processes, biofilms/biofilters for vapor-phase wastes, and composting. Emphasis is placed on modeling and design. Advantages and disadvantages of each application are compared. Case studies are presented in the areas of biosensors in environmental analysis, molecular biology applications in environmental engineering, and genetic engineering of organisms for bioremediation.

**Prerequisite**: Prior course work in environmental microbiology or biochemical engineering is recommended but not required.

**Instructors**: Durant, Wilson-Durant

**Offered**: Summer (even years)

### 575.704 Applied Statistical Analyses and Design of Experiments for Environmental Applications

This course introduces statistical analyses and techniques of experimental design appropriate for use in environmental applications. The methods taught in this course allow the experimenter to discriminate between real effects and experimental error in systems that are inherently noisy. Statistically designed experimental programs typically test many variables simultaneously and are very efficient tools for developing empirical mathematical models that accurately describe physical and chemical processes. They are readily applied to production plant, pilot plant, and laboratory systems. Topics covered include fundamental statistics; the statistical basis for recognizing real effects in noisy data; statistical tests and reference distributions; analysis of variance; construction, application, and analysis of factorial and fractional-factorial designs; screening designs; response surface and optimization methods; and applications to pilot plant and waste treatment operations. Particular emphasis is placed on analysis of variance, prediction intervals, and control charting for determining statistical significance as currently required by federal regulations for environmental monitoring.

**Instructor**: Bodt

**Offered**: Summer

### 575.706 Biological Processes for Water and Wastewater Treatment

This course develops the fundamentals and applications of aerobic and anaerobic biological unit processes for the treatment of municipal and industrial wastewater. The principles of activated sludge, aeration and clarifier design, fixed film reactors, anaerobic treatment, solids handling and treatment, land treatment, and nutrient removal are presented. This course uses concepts from microbiology, and the basic principles of stoichiometry, energetics, and microbial kinetics are used to support the design of biological unit processes.

**Prerequisite**: 575.405 Principles of Water and Wastewater Treatment.

**Instructor**: Weiss

**Offered**: Spring

### 575.707 Environmental Compliance Management

The course covers compliance with environmental laws and regulations by industry, small business, government facilities, and others. It includes legal responsibilities, environmental management systems, and practices such as audits and information systems and development of corporate policies and procedures that rise to the daunting challenge to harmonize the institution's primary goals with its environmental obligations. Several dimensions of environmental management are discussed: federal, state, and local regulation; scientific/technical factors; public relations and the press; and institutional objectives including economic competitiveness.

**Instructor**: Riegel

**Offered**: Spring

### 575.708 Open Channel Hydraulics

The course covers application of the principles of fluid mechanics to flow in open channels. Topics include uniform flow, flow resistance, gradually varied flow, flow transitions, and unsteady flow. The course also addresses flow in irregular and compound channels, backwater and 2D flow modeling, and applications to channel design and stability.

**Prerequisite**: 575.401 Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

**Instructor**: Naghash

**Offered**: Summer

### 575.710 Financing Environmental Projects

This course treats the financing of projects from two complementary perspectives: that of a government agency funding source and that of an environmental utility (water, wastewater, solid waste) that needs funds for its project. It discusses grants, concessionary loans, market loans, and loan guaranties, along with their relative desirability and efficiency. Because grant funding is never available for all projects, the course deals extensively with borrowing/lending. It discusses strategies for maximizing utility income, including appropriate tariff structures and the reform of government subsidy policy from supply-based general subsidies to demand-based targeted subsidies. Operational strategies to maximize income are also discussed, such as techniques to improve billing and collections, reduce losses, and reduce energy costs. Traditional cash flow analyses are used to determine debt service capabilities. Various project cost reduction strategies, such as staging and scaling, are introduced. Grants in the form of up-front project cost buy-downs vs. annual debt service subsidies are compared. Finally, several examples of project financing combining many of the elements introduced during the course are presented and analyzed.

**Instructor**: Tucker

**Offered**: Summer

### 575.711 Climate Change and Global Environmental Sustainability

This is a multidisciplinary course that focuses on the critical assessment of science, impacts, mitigation, adaptation, and policy relevant to climate change and global environmental sustainability. The first half of the class addresses climate change science; vulnerability and existing evidence and observations of the impacts of climate change; models and predictions of potential physical, ecological, and anthropological impacts; technological, economic, political, and consumer driven mitigation and adaptation strategies; and past and present local, state, federal, and international policy and legislation. The second half of the course actively investigates concepts and aspects of environmental sustainability, including the review of international assessments and reports and the analyses of relevant implications for human health, natural resources, energy supply and demand, and waste/pollution. This course stresses active learning and critical thinking. It requires both the objective and subjective analyses of an array of environmental sustainability and climate change topics and materials. Students will be required to participate in a climate change summit simulation, critically review climate change documentaries and complete an original timely and relevant sustainability case study. Students will also be required to complete quantitative technical assignments; research popular press, governmental agency, and peer-reviewed scientific literature; and participate in class discussions, presentations and exercises.

**Instructor**: Robert

**Offered**: Spring

### 575.713 Field Methods in Habitat Analysis and Wetland Delineation

This course provides students with practical field experience in the collection and analysis of field data needed for wetland delineation, habitat restoration, and description of vegetation communities. Among the course topics are sampling techniques for describing plant species distributions, abundance and diversity, including the quadrat and transect-based, point-intercept, and plot-less methods; identification of common and dominant indicator plant species of wetlands and uplands; identification of hydric soils; and the use of soil, topographic and geologic maps and aerial photography in deriving a site description and site history. Emphasis is placed on wetland vegetation, delineation and restoration. While many of the field examples are centered in the Maryland and Washington, DC region, the Gformat is designed so that the student performs field work in the state, country or region in which he or she would like to specialize.

**Prerequisite**: 575.415 Ecology.

**Instructor**: Hilgartner

**Offered**: Summer

### 575.714 Water Resources Management

This multidisciplinary course examines the scientific, institutional, and analytical aspects of managing water quantity and quality. Students are provided a historical context that is useful for assessing current policy. The water cycle and basic hydrology are reviewed. The course surveys the laws and regulatory instruments for managing water quantity and quality, which operate across federal, state, and local levels of government. Funding issues associated with water resources management include operating and capital budgets, debt financing, the challenges of pricing and the role of privatization. The course addresses the management of water demand and supply in the United States by economic sector and by in-stream and off-stream uses. This includes trends in water demand and supply, as well as modeling methods for water supply management. Fundamentals of flood and drought management are covered, with attention given to the context of global climate change and extreme events. The critical role of the general public in water resource management decision making is addressed in the context of structured techniques involving economic analyses, multi-objective analyses, and collaborative decision making. Water quality-based management under the federal Clean Water Act includes the topics of water quality standards, water quality assessments, total maximum daily loads (TMDLs), and ensuing permit requirements. Regional ecological water resources management is addressed for the Susquehanna River and by contrasting the Chesapeake Bay case with other large-scale cases.

**Instructors**: George, Williams

**Offered**: Summer

### 575.715 Subsurface Fate and Contaminant Transport

This course provides an introduction to the concepts relating to the nature and sources of environmental contaminants in the subsurface, the role of groundwater and soil water in mobilizing and spreading contamination, the processes that control distribution and fate of subsurface contamination, the accepted methods of investigating and analyzing contamination, and the analytical techniques that can be employed to model contaminant fate and transport in the subsurface. The course also considers surface water contamination caused by contamination in the groundwater. Computer laboratories of groundwater model simulations and solute transport solutions are used.

**Instructor**: Hilpert

**Offered**: Spring

### 575.716 Principles of Estuarine Environment: The Chesapeake Bay Science and Management

The course examines the basic physical, chemical, and biological components of the Chesapeake Bay ecosystem and how they interrelate in both healthy and degraded states of an estuary. The course focuses on the tidal waters of the Chesapeake Bay and its tributaries. It also covers the relationships of the Bay with the surrounding watershed, atmosphere, and ocean as well as relevance to other coastal systems. Particular emphasis is given to anthropogenic stresses such as nutrient and contaminant pollution, habitat modification, and harvest of fish and shellfish. The most current Chesapeake Bay management issues and policies being pursued at the federal, state, and local levels of government are discussed in depth, including their scientific foundation.

**Instructor:** Summers

**Offered:** Fall

### 575.717 Hydrology

This course reviews components of the hydrologic cycle, including precipitation, evapotranspiration, infiltration, subsurface flow, and runoff. Analysis of hydrologic data, including frequency analysis and the use of stochastic models for describing hydrologic processes, is also covered.

**Prerequisite**: 575.401 Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

**Instructor**: Raffensperger

**Offered**: Spring

### 575.720 Air Resources Modeling and Management

This course is a comprehensive overview of air resources modeling and management. Topics covered in this course include an introduction to particulate matter and gas-phase pollutant chemistry and physics; an overview of atmospheric motion to give students a sense of how air pollutant transport and transformation is modeled; air pollution modeling fundamentals and applications; an assessment of air pollution exposure, health effects, and toxicological and epidemiological considerations; regulatory considerations in air pollution control related to model selection and use; and a brief overview of air pollution control technologies and specific considerations relative to indoor air quality and climate change. Specific air pollution problems addressed in the course include those involving the state of air pollution at local, regional, and national scales; air pollution problems from a public health perspective; and system analytic approaches for developing air pollution control strategies for particulate matter, tropospheric ozone, acid rain, carbon monoxide, nitrogen oxides, and greenhouse gases. A term-long case study assignment is required that will leverage these course elements against a relevant real-world air pollution scenario.

**Instructors**: Ellis, Robert

**Offered**: Fall

### 575.721 Air Quality Control Technologies

This is a multidisciplinary course that involves the applications of chemistry, thermodynamics, and fluid mechanics in the selection and design of air pollution control equipment. Topics include the estimation of potential pollutants, chemical characterization of gas streams to be controlled, theory and practice of air pollution control, and design and costing of control technologies. The course emphasizes the design of systems to reduce particulate matter emissions, volatile organic compound (VOC) emissions, nitrogen oxide emissions, and sulfur dioxide emissions.

**Prerequisites**: 575.401 Fluid Mechanics or an equivalent course in fluid flow; an undergraduate course in thermodynamics.

**Instructor**: Robert

**Offered**: Summer

### 575.722 Sensor Application for Environmental Exposure Monitoring

The primary objective of this course is to present the fundamentals of sensor design in the application of environmental monitoring. The course will examine the basic sensor design and operation in specific environmental applications including ambient, built, personal and social. Other topics to be covered include, data capture, storage, transmission and analysis and the legal and policy requirements for environmental monitoring with sensors.

**Instructor**: Dellarco

### 575.723 Sustainable Development and Next Generation Buildings

The course will introduce the concepts, applications, and tools for analysis and decision making in support of sustainable environmental development and next-generation communities and building design. Students will be introduced to a variety of challenges related to environmental protection, stewardship, and management of air, soil, and water. The underlying principles of ecological protection, stewardship, reduced environmental footprint, ecosystem capital, sustainable economic development, and globalization impacts will be reviewed. The integration of actions that are ecologically viable, economically feasible, and socially desirable to achieve sustainable solutions will be evaluated. Within this context, sustainable building concepts will be explored that are intended to provide throughout their lifetime a beneficial impact on their occupants and their surrounding environment. Such buildings are optimally integrated on all parameters–initial affordability, timeliness of completion, net life-cycle cost, durability, functionality for programs and persons, health, safety, accessibility, aesthetic and urban design, maintainability, energy efficiency, and environmental sustainability. The principles of LEED building design and certification will also be introduced and example projects reviewed. Integrated design and construction practices that significantly reduce or eliminate the negative impact of buildings on the environment and occupants will be assessed in the broad areas of (1) sustainable site planning, (2) safeguarding water and water efficiency, (3) energy efficiency and renewable energy, (4) conservation of materials and resources, and (5) indoor environmental quality. A critical element for a successful sustainable building policy and program is an integrated building planning and design process. Integrated planning and design refers to an interactive and collaborative process in which all stakeholders are actively involved and communicate with one another throughout the design and construction practice. These processes will also provide a broader understanding of sustainable options for infrastructure changes that may occur in various BRAC planning and implementation situations. A number of case studies will be examined to gain an understanding of application issues.

**Instructor**: Roper

**Offered**: Summer

### 575.727 Environmental Monitoring and Sampling

Environmental monitoring and sampling provide the data foundation required for assessments of (a) compliance with environmental criteria and regulatory permits, and (b) status and trends to evaluate the effectiveness of legislation and regulatory controls. The overall objective of the course is to prepare a Sampling and Analysis Plan (SAP) as a course project to support a site-specific field data collection program that includes environmental sampling for air, surface water, groundwater and soils. An overview of historical and current environmental issues, including public health and environmental impacts, for air, surface water, groundwater and soil contamination, is presented. Regulatory requirements of the major statutes that govern various media are presented, along with assessments of the effectiveness of legislation including the Clean Water Act, Clean Air Act, Safe Drinking Water Act, CERCLA, and RCRA.

The course describes sources and physical, chemical and biological processes that govern distributions of contaminants in air, surface water, groundwater and soils. The course examines the principles, methods and strategies for monitoring and discrete sampling of environmental media, including air, surface water, groundwater and soil. Sampling methods include overviews of current methods for discrete sampling, automated data acquisition and remote sensing for air, surface water, groundwater and soils. Requirements of a SAP will be presented, including key elements of a Quality Assurance Project Plan (QAPP) and a Field Sampling Plan (FSP.) The course presents key concepts of statistics for sampling design, data variability, analysis and interpretation of data sets. The course includes an introduction to data sources available from national databases for air, surface water, groundwater and soils. Analysis, presentation and interpretation of data sets include use of GIS/mapping, data management methods and statistical analyses to support decision-making, site characterization and evaluation of status and trends. Where feasible, the online course will provide the opportunity for students to participate in local field trips, or observe field sampling methods for air, surface water, groundwater and soils.

**Instructor**: Stoddard

**Offered**: Fall

**575.728 Sediment Transport and River Mechanics**

This course examines the processes of sediment entrainment, transport, and deposition and the interaction of flow and transport in shaping river channels. Topics reviewed include boundary layer flow; physical properties of sediment; incipient, bed-load, and suspended-load motion; bed forms; hydraulic roughness; velocity and stress fields in open channels; scour and deposition of bed material; bank erosion; and size, shape, platform, and migration of river channels. In addition, the course develops techniques of laboratory, theoretical, and numerical modeling and applies them to problems of channel design, restoration, and maintenance.

**Prerequisite**: Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

**Instructor**: Baker, Sholtes

**Offered**: Fall

**575.730 Geomorphic and Ecologic Foundations of Stream Restoration**

This course presents principles from hydrology, sedimentation engineering, geomorphology, and ecology relevant to the design and evaluation of stream restoration projects. A watershed context is emphasized in developing the background needed to assess different design approaches. After developing a common foundation in stream dynamics, the course considers trade-offs among restoration objectives, the merits of analog and predictive approaches, the role of uncertainty in restoration design, and metrics for assessing ecological recovery. The course includes online discussions, design exercises, review papers, and finishes with an assessment of a stream in your geographic region.

**Instructors**: Baker, Sholtes

**Offered**: Spring

**575.731 Water Resources Planning**

The course will discuss the application and interrelationships among microeconomics, ecology, hydrology, and related fields to the planning and management of water systems. Topics will include flood control, navigation, hydroelectric power, water supply, environmental restoration, multi-objective planning, and urban water resource management. The course will demonstrate the process for planning a water resource project, including identifying the problems and opportunities, inventorying and forecasting conditions, formulating alternative plans, evaluating alternative plans, comparing alternative plans, and selecting a plan. Particular attention will be paid to the appropriate interdisciplinary approach to plan formulation.

**Instructor**: Kranzer

**Offered**: Fall

**575.733 Energy Planning and the Environment**

This course examines the interrelationships between the environment and the ways in which energy is produced, distributed, and used. Worldwide energy-use patterns and projections are reviewed. Particular attention is paid to the electrical and transportation sectors of energy use. Underlying scientific principles are studied to provide a basis for understanding the inevitable environmental consequences of energy use. Topics studied include fossil, nuclear, and existing and potential renewable sources, including hydroelectric, geothermal, tidal, wind, and solar. Transportation options including internal combustion, hybrid, and electric options are quantitatively compared. Use of alternate fuels such as biodiesel and ethanol are evaluated. Emphasis is placed on the environmental impacts of energy sources, including local effects resulting from emissions of nitrogen oxides, sulfur, hydrocarbons, and particulates as well as global effects such as mercury release from coal combustion. Carbon emissions are a continuing theme as each energy technology is studied and its contribution to climate change is assessed. Carbon suppression schemes are examined. Particular attention is paid to consequences and effectiveness of government intervention and regulation. The purpose is to help students understand how energy is converted into useful forms, how this conversion impacts our environment, and how public policy can shape these impacts.

**Prerequisite**: 575.411 Economic Foundations for Public Decision Making or an equivalent course in microeconomic theory is recommended.

**Instructor**: Lightner

**Offered**: Summer

**575.734 Smart Growth Strategies for Sustainable Urban Development and Revitalization**

This course addresses the concepts, practices, and tools for smart growth sustainable urban planning and provides an understanding for how to apply these to urban communities. The sustainable urban development is a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present but also for future generations to come. In other words, it is the development and restoration of urban areas that will meet the needs of the present without compromising the ability of future generations to meet their own needs. The course addresses a number of urban design concepts for smart growth and sustainable development, including balanced land use planning principles; importance of an overall transportation strategy; providing urban tree coverage; leveraging public transportation accessibility; providing a spectrum of housing availability; integration of office, retail, and housing units; reduction of urban area environmental footprint; use of recycled, reused, reusable, green, and sustainable products; integration of renewable solar energy and wind power into buildings and government systems; transit-oriented development; innovative low-impact storm water management practices; reduction in urban heat island effects; urban water resource management; and energy efficiency and conservation.

**Instructor**: Roper

**Offered**: Fall

### 575.737 Environmental Security with Applied Decision Analysis Tools

This multi-disciplinary course examines current and emerging environmental security issues at multinational, national, and regional scales. These issues are approached from the perspective of decision-making for policy, planning, and management. The course begins with an overview and definitions of environmental security within the context of present global demographic patterns, use of natural resources, and climate change. The theory and principles of multi-criteria decision analysis (MCDA) are reviewed, using environmental security examples to illustrate concepts. Three MCDA methodologies are presented, including multi-attribute weighting, Analytic Hierarchy Process, and outranking, which are commonly used to assist decision makers. The MCDA approach is critiqued from the perspective of measurement theory and guidelines for MCDA use are suggested. With both the social sciences and natural sciences providing a framework, several specific environmental security topics are covered in greater depth: energy; air quality; ecosystems and biodiversity; fresh water; agriculture and food; and sea level rise. Within these topics, students will develop MCDA models for particular policy, planning, and management problems under the guidance of the instructors. The course concludes by considering the prospects for environmental security and sustainability in the coming decades.

**Instructors**: Williams, Wolman, Zachary

**Offered**: Spring

### 575.742 Hazardous Waste Engineering and Management

The course addresses traditional and innovative technologies, concepts, and principles applied to the management of hazardous waste and contaminated sites to protect human health and the environment. Topics include regulatory requirements; fate and transport of contaminants; physical, chemical, and biological treatment; land disposal restrictions; guidelines for design, construction, and closure of hazardous waste landfills; environmental monitoring systems; management of medical waste and treatment options; management of underground and aboveground storage tanks; toxicology and risk assessment; pollution prevention and waste minimization; hazardous waste generators and transporters; permitting and enforcement of hazardous waste facilities; closure and financial assurance requirements; and RCRA Subtitle C Corrective Action and CERCLA/Superfund/Brownfields site remediation processes.

**Instructors**: Alavi, Kim, Overcash

**Offered**: Spring

### 575.743 Atmospheric Chemistry

Earth's atmosphere is a vital and fragile component of our environment. This course covers the chemical composition of the atmosphere and the principles of chemistry that control the concentrations of chemical species. Following an introduction to the atmosphere, including its structure and composition, the course investigates basic concepts relating to atmospheric chemical kinetics and photochemistry. This foundation of chemistry and physics is applied to the study of the gas-phase chemistry of the troposphere and the stratosphere including focused study of criteria pollutants such as carbon monoxide (CO), tropospheric and stratospheric ozone (O3), chlorinated fluorocarbons (CFCs), sulfur and nitrogen oxides (NOx and SOx) and particulate matter (PM). Many trace species and their impacts on atmospheric chemistry are investigated. Condensed-phase chemistry topics include aqueous-phase chemistry, the chemistry of clouds and fogs and aerosol chemistry (including particulate matter chemistry). The chemistry of climate change and the radiative forcing of atmospheric constituents is studied. The relationship between atmospheric chemistry and air quality is stressed via focusing on negative human health and environmental impacts. The course stresses application of these concepts to current and relevant atmospheric chemistry issues.

**Instructors**: Jakober, Robert

**Offered**: Spring

### 575.744 Environmental Chemistry

This course focuses on the environmental behavior and fate of anthropogenic contaminants in aquatic environments. Students learn to predict contaminant properties influencing contaminant transfers between hydrophobic phases, air, water, sediments, and biota, based on a fundamental understanding of physico-chemical properties, intermolecular interactions, and basic thermodynamic principles. Mechanisms of important transformation reactions are also discussed and techniques and quantitative models for predicting the environmental fate or human exposure potential of contaminants are discussed.

**Instructor**: Jayasundera

**Offered**: Fall

**575.745 Physical and Chemical Processes for Water and Wastewater Treatment**

In this course, mass and momentum transport, aquatic chemistry, and chemical reaction engineering are applied to physical and chemical processes used for water and wastewater treatment. Students also learn the theory and practice of various unit processes including disinfection, oxidation, coagulation, sedimentation, filtration, adsorption, gas transfer, and membrane filtration. The goal is to provide a theoretical understanding of various chemical and physical unit operations, with direct application of these operations to the design and operation of water and wastewater treatment systems. Students will use the concepts learned in this class to better understand the design and operation of engineered and natural aquatic systems.

**Prerequisites**: 575.405 Principles of Water and Wastewater Treatment.

**Instructor**: Arora

**Offered**: Fall

**575.746 Water and Wastewater Treatment Plant Design**

This course familiarizes students with appropriate design criteria and the design process for water and wastewater treatment plants. This includes design of treatment processes, cost estimates, and a working design team under project managers. Additional course requirements include oral presentations and writing engineering reports.

**Prerequisites**: 575.405 Principles of Water and Wastewater Treatment and either 575.706 Biological Processes for Water and Wastewater Treatment or 575.745 Physical and Chemical Processes for Water and Wastewater Treatment.

**Instructor**: Davies-Venn

**Offered**: Summer

**575.747 Environmental Project Management**

This course educates students on the key elements of an integrated approach to environmental project management, an endeavor that requires expertise in scientific, engineering, legal, public policy, and project management disciplines. Emphasis is placed on critical factors that are often unique to a major environmental project, such as the uncertainty surrounding scope definition for environmental cleanup projects and the evolving environmental regulatory environment. The students learn to develop environmental project plans, establish project organization and staffing, define management functions, develop time management approaches, resolve project conflicts, determine project effectiveness, implement integrated project management techniques such as the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM) as they relate to environmental project management, perform pricing and cost estimating, establish cost control, set priorities, and perform trade-off analyses. The course uses environmental project case studies to examine the integrated nature of environmental project management. Examples of topics to be covered in this case study format include environmental security projects, environmental technology deployment projects, privatization of governmental environmental projects, and pollution prevention/waste minimization projects.

**Instructor**: Toussaint

**Offered**: Fall

**575.748 Environmental Management Systems**

This course gives engineering students a thorough grounding in environmental management systems (EMS), which constitute the primary environmental interface between the engineering profession and private industry. EMS consist of a core set of actions designed to (1) reduce the use of water, energy, and nonrenewable resources; (2) reduce air and water pollution caused by a firm's operations; and (3) assure compliance with environmental rules and regulations. Companies also use EMS to improve their corporate image, resulting in increasing sales to environmentally conscious customers, attracting investment from Socially Responsible Investment (SRI) funds, generating favorable public opinion, and improving employee morale. Topics discussed include "greening the supply chain," life cycle analysis (LCA), the Leadership in Energy & Environmental Design (LEED) program for buildings, the Energy Star program for energy management, and the ISO 14000 program for environmental certification. The course will also discuss important, but less well-known, EMS strategies such as the impact of green roofs on HVAC costs or the impact of water costs from gray water management systems, all of which are well documented by government and other organizations.

**Instructor**: Curley

**Offered**: Fall

**575.750 Environmental Policy Needs in Developing Countries**

This course will provide students with a thorough understanding of environmental policy needs in developing countries. The world's fastest growing economies are located in developing countries where rapid urbanization and use of natural resources will require supporting infrastructure. However, there are factors that may encourage or limit this growth, including the country's economic structure, governance, cultural history, demographics, and social structure. Through lectures, research and group exercises, the students will (1) explore the social, economic and environmental issues that challenge the developing world as they move toward advancing their economies, infrastructure and governance systems; (2) analyze how the various issues are interconnected and understand how this interconnectedness may affect environmental policy making and (3) apply critical thinking to the analysis of environmental policy in order to effectively challenge classical assumptions. The student will be expected to analyze a specific environmental issue facing a developing country or region and develop a policy framework to address this issue.

**Instructors**: Kopsick, Schappelle

**Offered**: Spring

### 575.752 Environmental Justice and Ethics Incorporated into Environmental Decision-Making

This course focuses on the environmental justice and ethics problems facing environmental engineers, planners, and managers. It explores the foundations of the environmental justice movement, current and emerging issues, and the application of environmental justice analysis to environmental policy and planning. It examines claims made by diverse groups along with the regulatory and government policy responses that address perceived inequity and injustice. The course will study the mechanisms that give rise to class, racial, and other kinds of disparities that impact environmental decision-making. This includes the study of affected constituents, communities, industry, government, environmental activists, policymakers, and scholars, to learn about the causes and consequences of inequitable distributions of environmental benefits and hazards. Students will learn about various methods for researching environmental justice issues and strategies for formulating policies and collaborating with communities. In this course, students will review environmental justice theories and perspectives as case studies of Black Americans, Hispanic Americans, and Native American Nations. The class will include mainly a United States focus, but include aspect of the international issues and perspectives through research projects.

**Instructor**: Tzoumis

**Offered**: Spring

### 575.753 Communication of Environmental Information and Stakeholder Engagement

This course provides students with the skills for communicating scientific environmental data and sustainable engineering design to stakeholders, including scientists in different fields, policy decision-makers, and the interested public. The course covers the importance of clear communication of complex scientific information for the development and acceptance of technologies, public policy, and community-based environmental initiatives. The key stakeholders for environmental engineers, scientists, and managers are specified. Methods of engagement and designing key messages are defined for global, national, and local issues of student interest. Major types of communication media are covered, including written communication and graphics, online communications in short and long-form new media, and interactive communications such as surveys and citizen science to involve stakeholders in the creation and analysis of big data and dispersed information. The emphasis of the course is from the point of view of an environmental professional (not marketing professional) and developing an effective science-based communications portfolio to share complex scientific information with a broad range of interested parties.

**Instructor**: Engel-Cox

**Offered**: Spring

### 575.759 Environmental Policy Analysis

The course explores the problem of developing appropriate public policies for the primary purpose of restoring, preserving, and protecting aspects of the physical environment. Emphasis is placed on the need to harmonize environmental science, human health, sociopolitical, technological, legal, financial, and economic considerations in a context of incomplete information and uncertain futures. At least one specific environmental policy is studied in the course of the semester. Students are expected to plan and execute individual research projects that demonstrate the use of quantitative and/or economic tools in designing and evaluating responses to environmental management problems.

**Instructor**: Boland, Norman

**Offered**: Fall

### 575.763 Nanotechnology and the Environment: Applications and Implications

This course explores the positives and negatives of nanotechnology: the benefits to use in commercial and environmental applications, as well as considering nanoparticles as an emerging environmental contaminant. The course will analyze nanotechnology through an interdisciplinary outlook for a life-cycle analysis. This analysis will begin with synthesis, manufacturing, unintentional releases, and disposal. We will consider ecological consequences and public health implications of the use of nanotechnology. Students will learn the science behind nanotechnology and how nanoparticle characteristics impact transport in the environment, including human exposure assessment, and a discussion of current measurement tools. Policies regulating nanotechnology and risk assessment will be addressed.

**Instructor**: Chalew

**Offered**: Spring

**575.801 Independent Project in Environmental Engineering, Science, and Management**
This course provides students with an opportunity to carry out a significant project in the field of environmental engineering, science, technology, planning, or management as a part of their graduate program. The project is individually tailored and supervised under the direction of a faculty member and may involve conducting a semester-long research project, an in-depth literature review, a non-laboratory study, or application of a recent development in the field. The student may be required to participate in conferences relevant to the area of study. To enroll in this course, the student must be a graduate candidate in the Environmental Engineering, Science, and Management program within the latter half of the degree requirements and must obtain the approval and support of a sponsoring faculty member in the Department of Geography and Environmental Engineering. The proposal description and completed required forms must be submitted prior to registration for approval by the student's advisor and the program chair. A maximum of one independent project course may be applied toward the master's degree or post-master's certificate.

**Course Note**: This course must be completed with a member of the research faculty of the Department of Geography and Environmental Engineering.

**Offered**: Fall, Spring, Summer

# APPLIED BIOMEDICAL ENGINEERING

**585.207 Molecular Biology**
The course is intended to serve as a fundamental introduction to cell and molecular biology. Topics generally included are basic chemistry and biochemistry of the cell; structure, function, and dynamics of macromolecules; cell organization; enzyme kinetics; membranes and membrane transport; biochemistry of cellular energy cycles, including oxidative phosphorylation; replication, transcription, and translation; regulation of gene expression; and recombinant DNA technology. Where appropriate, biomedical application and devices based on principles from cell and molecular biology are emphasized.

**Prerequisite**: 585.209 Organic Chemistry.

**Course Note**: Not for graduate credit.

**Instructors**: DiNovo-Collela, Potember

**Offered**: Spring

**585.209 Organic Chemistry**
This course offers an in-depth review and study of organic chemistry. Topics include the fundamental chemistry of carbon compounds, chemical bonding, synthesis, reaction mechanisms, and stereochemistry. The role of organic chemistry in biology and medicine, environmental science, and industry is discussed.

**Course Note**: Not for graduate credit.

**Instructor**: Potember

**Offered**: Summer

**585.405 Physiology for Applied Biomedical Engineering**
This two-semester sequence is designed to provide the physiological background necessary for advanced work in biomedical engineering. A quantitative model-oriented approach to physiological systems is stressed. First-term topics include the cell and its chemistry, transport and the cell membrane, properties of excitable tissue and muscle, the cardiovascular system, and the respiratory system. The second-term course covers anatomy of the nervous system, structure and functions of the auditory and visual systems, motor systems, the kidney and gastrointestinal tract, and the neural and neuroendocrine control of the circulation.

**Instructors**: Berman, Haase, Faculty

**Offered**: Fall, Spring

**585.406 Physiology for Applied Biomedical Engineering**
This two-semester sequence is designed to provide the physiological background necessary for advanced work in biomedical engineering. A quantitative model-oriented approach to physiological systems is stressed. First-term topics include the cell and its chemistry, transport and the cell membrane, properties of excitable tissue and muscle, the cardiovascular system, and the respiratory system. The second-term course covers anatomy of the nervous system, structure and functions of the auditory and visual systems, motor systems, the kidney and gastrointestinal tract, and the neural and neuroendocrine control of the circulation.

**Instructors**: Berman, Haase, Faculty

**Offered**: Fall, Spring

**585.408 Medical Sensors and Devices**
This course covers the basic and advanced principles, concepts, and operations of medical sensors and devices. The origin and nature of measurable physiological signals are studied, including chemical, electrochemical, optical, and electromagnetic signals. The principles and devices to make the measurements, including a variety of electrodes and sensors, will be discussed first. This will be followed by a rigorous presentation of the design of appropriate electronic instrumentation. Therapeutic instrumentation such as pacemakers, defibrillators, and prosthetic devices will be

reviewed. The final part of this course will cover emerging frontiers of cellular and molecular instrumentation and the use of micro- and nanotechnology in these biotechnology fields. The lectures will be followed by realistic experimentation in two laboratory sessions where students will obtain hands-on experience with electronic components, sensors, biopotential measurements, and testing of therapeutic instrumentation.

**Instructors**: Thakor, Faculty

### 585.409 Mathematical Methods for Applied Biomedical Engineering

The course covers mathematical techniques needed to solve advanced problems encountered in applied biomedical engineering. Fundamental concepts are presented, with emphasis placed on applications of these techniques to biomedical engineering problems. Topics include solution of ordinary differential equations using the Laplace transformation, Fourier series and integrals, solution of partial differential equations including the use of Bessel functions and Legendre polynomials, and an introduction to complex analysis.

**Prerequisite**: Familiarity with multivariable calculus, linear algebra, and ordinary differential equations.

**Instructor**: Rio

**Offered**: Fall

### 585.411 Principles of Medical Instrumentation and Devices

This course covers the basic and advanced principles, concepts, and operations of medical sensors and devices. The origin and nature of measurable physiological signals are studied, including chemical, electrochemical, optical, and electromagnetic signals. The principles and devices to make the measurements, including a variety of electrodes and sensors, will be first discussed. This will be followed by a rigorous presentation of the design of appropriate electronic instrumentation. Therapeutic instrumentation such as pacemakers, defibrillators, and prosthetic devices will be reviewed. The final part of this course will cover emerging frontiers of cellular and molecular instrumentation and the use of micro- and nanotechnology in these biotechnology fields. The lectures will be followed by realistic experimentation in two laboratory sessions where students will obtain hands-on experience with electronic components, sensors, biopotential measurements, and testing of therapeutic instrumentation.

**Instructor**: Maybhate

**Offered**: Spring

### 585.414 Rehabilitation Engineering

This course is an introduction to a field of engineering dedicated to improving the lives of people with disabilities. Rehabilitation engineering is the application of engineering analysis and design expertise to overcome disabilities and improve quality of life. A range of disabilities and assistive technologies will be investigated. The relationship between engineering innovation, the engineering design process, the human–technology interface, and the physical medicine and rehabilitation medical community will be explored. This course will require a semester long design project that addresses an unmet technological need. Students will choose a project with the instructor's approval. An engineering solution will be developed over the course of the semester through specification development, design reviews, and interacting with appropriate members of the medical community. There is a required visit to a local rehabilitation facility. For students who complete a software training module, access to a 3D printer will be available with assistance from an experienced designer.

**Prerequisite**: An undergraduate engineering degree or permission of the instructor.

**Instructor**: Smith

**Offered**: Spring

### 585.423 Systems Bioengineering Lab

A two-semester laboratory course in which various physiological preparations are used as examples of problems of applying technology in biological systems. The emphasis in this course is on the design of experimental measurements and on physical models of biological systems.

**Prerequisite**: 585.405 Physiology for Applied Biomedical Engineering.

**Course Note**: This course counts as a one-half course.

**Instructor**: Haase

**Offered**: Fall and Spring

### 585.424 Systems Bioengineering Lab

A two-semester laboratory course in which various physiological preparations are used as examples of problems of applying technology in biological systems. The emphasis in this course is on the design of experimental measurements and on physical models of biological systems.

**Prerequisite**: 585.406 Physiology for Applied Biomedical Engineering and 585.423 Systems Bioengineering Lab.

**Course Note**: This course counts as a one-half course.

**Instructor**: Haase

**Offered**: Fall and Spring

### 585.425 Biomedical Engineering Practice and Innovation

This course will cover hands-on experimental and design work primarily in the areas of physiology, cell and tissue engineering and biomedical instrumentation. In addition to teaching and allow students to perform state-of-the art experimental techniques, this course will emphasize the business end of biomedical engineering innovation including identification of engineered needs and FDA regulation.

**Prerequisite**: 585.405 and 585.406 Physiology for Applied Biomedical Engineering and 585.409 Mathematical Methods for Applied Biomedical Engineering or 535.441 Mathematical Methods for Engineers must be completed.

**Course Note**: This course is a combination online course and residency program at the Homewood campus.

**Instructor**: Logsdon

**Offered**: Summer

### 585.604 Principles of Medical Imaging

With an emphasis on the physical principles behind modern medical imaging, this online course will cover topics such as mathematical and physical foundations of imaging; image construction and interpretation; image quality and image processing. Individual modules will cover various imaging modalities to provide an advanced understanding of the physics of the signal and its interaction with biological tissue; image formation or reconstruction; modality specific issues for image quality; clinical applications; biological effects and safety. Final modules will briefly touch upon image analysis and describe applications for clinical diagnosis and/or treatment.

**Prerequisites**: 585.409 Mathematical Methods for Applied Biomedical Engineering or 535.441 Mathematical Methods for Engineers, or permission from the instructor. An introductory background in physics (electromagnetism) is recommended.

**Course Note**: An introductory background in physics (electromagnetism) is recommended.

**Instructors**: Maybhate, Williams

### 585.605 Medical Imaging

This course examines fundamental physical concepts, instrumentation, and signal processing techniques used to produce images in radiography, ultrasonography, tomography, magnetic resonance imaging, and nuclear medicine.

**Prerequisite**: 585.409 Mathematical Methods for Applied Biomedical Engineering or equivalent.

**Instructors**: Fainchtein, Faculty

**Offered**: Fall (odd years)

### 585.606 Medical Image Processing

This course covers digital image processing techniques used for the analysis of medical images such as x-ray, ultrasound, CT, MRI, PET, microscopy, etc. The presented image enhancement algorithms are used for improving the visibility of significant structures as well as for facilitating subsequent automated processing. The localization and identification of target structures in medical images are addressed with several segmentation and pattern recognition algorithms of moderate complexity. Image reconstruction algorithms used for three-dimensional image formation are presented. The course covers image registration algorithms used to determine the correspondence of multiple images of the same anatomical structure. Image compression algorithms applied to medical images are also addressed.

**Prerequisites**: Familiarity with linear algebra and Fourier transforms.

**Instructors**: Bankman, Pham, Spisz

**Offered**: Spring (odd years)

### 585.607 Medical Imaging II: MRI

Following the increasing use and development of new MRI methods, a course on advanced MRI concepts and applications was designed as part of the imaging area of emphasis. This course provides more information on the physics, imaging procedures, and advanced techniques of MRI and also includes two lectures on nuclear medicine.

**Prerequisite**: 585.409 Mathematical Methods for Applied Biomedical Engineering or equivalent.

**Instructor**: Spencer

**Offered**: Summer

### 585.608 Biomaterials

This course covers the fundamentals of the synthesis, properties, and biocompatibility of metallic, ceramic, polymeric, and biological materials that come in contact with tissue and biological fluids. Emphasis is placed on using biomaterials for both hard and soft tissue replacement, organ replacement, coatings and adhesives, dental implants, and drug delivery systems. New trends in biomaterials, such as electrically conductive polymers, piezoelectric biomaterials, and sol-gel processing, are discussed, and the recent merging of cell biology and biochemistry with materials is examined. Case studies and in-class scenarios are frequently used to highlight the current opportunities and challenges of using biomaterials in medicine.

**Prerequisite**: 585.209 Organic Chemistry.

**Instructor**: Potember

**Offered**: Fall

### 585.609 Cell Mechanics

The class starts with introductory lectures on the place of cell mechanics in the broader areas of cell biology, physiology, and biophysics, where the general topics of cell structure, motility, force generation, and interaction with the extracellular matrix are considered. Three important case studies are discussed: blood cells, vascular endothelial cells, and cochlear hair cells. The analysis of each of these cases includes constitutive relations, experiments to estimate cellular parameters, and biological and physiological implications. The constitutive relations are based on nonlinear viscoelasticity in the cases of blood and endothelial cells and linear piezoelectricity in the case of hair cells. The necessary components of engineering mechanics of solids and fluids are introduced. The effective mechanical characteristics of the cell are related to the structure and properties of the cellular membrane, cytoskeleton, and nucleus. Micropipette aspiration, atomic force microscopy, and magnetic cytometry techniques are discussed in detail. Students also read and make presentations of original journal papers covering additional topics, which exposes them to the professional literature and hones their communication skills.

**Instructor**: Spector

**Offered**: Summer

### 585.610 Biochemical Sensors

This course covers the fundamental principles and practical aspects of chemical sensing of physiological signals. The focus of the course is on the electrochemistry and biophysical chemistry of biological sensing elements and their integration with signal transducers. Other topics covered include design and construction of practical sensors, processing and interpretation of signal outputs, and emerging technologies for biosensing.

**Instructors**: Bryden, Potember

**Offered**: Fall (odd years)

### 585.618 Biological Fluid and Solid Mechanics

The goal of this class is to teach the relation between the mechanics and physiology (biology) of tissues and cells. This relation is demonstrated by introducing general models of solid and fluid mechanics and applying them to the cardiovascular system and bones. In particular, the arterial wall and endothelial cell mechanics as well as bone anisotropic properties and remodeling are discussed. The course also shows how theoretical models are used to interpret experiments and how experimental data are used to estimate important parameters (constants) of the models. Experiments with biaxial stretching, micropipette aspiration, and atomic force microscopy commonly used to probe the mechanical properties of tissues and cells are discussed in detail. The models include anisotropic linear elasticity, nonlinear elasticity, viscoelasticity, and Newtonian (non-Newtonian) fluid dynamics.

**Instructor**: Spector

### 585.620 Orthopedic Biomechanics

This course serves as an introduction to the field of orthopedic biomechanics for the biomedical engineer. Structure and function of the musculoskeletal system in the intact and pathologic states will be reviewed. Further discussion will focus on the design of orthopedic implants for the spine and the appendicular skeleton. Biomechanical principles of fracture repair and joint reconstruction will also be addressed. Peer-reviewed journal publications will be used to explore the latest developments in this field.

**Prerequisite**: 585.405/406 Physiology for Applied Biomedical Engineering (or equivalent).

**Instructor**: Dimitriev

**Offered**: Fall (even years)

### 585.624 Neural Prosthetics: Science, Technology, and Applications

This course addresses the scientific bases, technologies, and chronic viability of emerging neuroprosthetic devices. Examples include cochlear and retinal implants for sensory restoration, cortical and peripheral nervous system and brain computer interface devices for deriving motor control and enabling afferent feedback, rehabilitative and therapeutic devices such as deep brain stimulators for Parkinson's disease, functional electrical stimulation systems for spinal cord injuries, and cognitive prosthetic systems for addressing brain trauma. Regulatory (FDA) challenges with emerging technologies and ethical considerations will also be addressed.

**Instructors**: Harshbarger, Faculty

**Offered**: Fall (even years)

### 585.629 Cell and Tissue Engineering

Cell and tissue engineering are dynamic and rapidly growing fields within biomedical engineering. This course will examine fundamental biological processes and medical engineering tools essential to regenerative medicine both at the single-cell and whole-organism level. Topics include stem cell engineering, cell–matrix and cell–scaffold interactions, cell–cell interactions and tissue morphogenesis, wound healing, and in vitro organogenesis.

**Prerequisites**: Knowledge of basic molecular and cellular biology, physiology, and math through ordinary differential equations is required.

**Instructor**: Drummond, Logsdon

**Offered**: Fall

**585.631 Advanced Signal Processing for Biomedical Engineers**

One of the defining topics for biomedical engineering, Signal Processing is playing an increasingly important role in the modern days mostly due to ever-increasing popularity of portable, wearable, implantable, wireless, miniature, medical sensors/devices. The primary function of all the medical devices is acquisition and analysis of some kind of physiological data, often in a semi-continuous real-time manner. From the medical stand-point the benefits that the devices offer pertain to complimenting the physician in diagnosis, prognosis and therapeutics. High quality signal processing algorithm is a vital part of each of this process. On the research side, accurate signal processing plays a fundamentally important role in a medical devices validation and translation from Bench to Bedside. Mastering this important topic can equip the student with skills that can be immediately applied in real-life technological innovations. This new online course will primarily focus on advanced topics in Signal Processing, including linear and non-linear analysis of primary electro-physiological signals. Topics will include more traditional, Auto-regressive Moving Average Analysis, spectral analysis, singular value decomposition as well as advanced methods such as entropy computation, dimensionality estimation, state-space reconstruction, recurrence time analysis, parameter estimation etc. Students will be challenged to write their own algorithms to reproduce select published research results.

**Prerequisites**: 585.409 Mathematical Methods for Applied Biomedical Engineering; 535.441 Mathematical Methods for Engineers; OR a written permission from the instructor. Knowledge of MATLAB is strongly recommended.

**Instructor**: Maybhate

**585.633 Biosignals**

This course introduces students to the realm of biological signals and their analysis using common tools of modern computer-based signal handling. Methods are developed to introduce students to diagnostic pattern recognition techniques using features derived from these analysis methods.

**Prerequisites**: 585.409 Mathematical Methods for Applied Biomedical Engineering or equivalent; 520.435 Digital Signal Processing or equivalent, a 300-level probability and statistics course

**Instructors**: Maybhate, Sherman

**Offered**: Spring

**585.634 Biophotonics**

This course introduces the fundamental principles of biophotonics and their applications to real-world devices. In a combination of laboratory and classroom exercises, students will design optical systems for evaluation of optical properties of biological media and learn computational methods to simulate light transport in such media. Modern optical measurement techniques including fluorescence spectroscopy, optical coherence tomography, and confocal microscopy will be covered in detail.

**Instructors**: Ramella-Roman, Sova

**Offered**: Spring

**585.800 Special Project in Applied Biomedical Engineering**

This course is an individually tailored, supervised project that offers the student research experience through work on a special problem related to the student's specialty of interest. The research problem can be addressed experimentally or analytically. A written report is produced on which the grade is based. The applied biomedical engineering project proposal form must be completed prior to registration.

**Prerequisite**: Permission of the instructor

**Instructor**: Faculty

**Offered**: All semesters

## ENGINEERING MANAGEMENT & TECHNICAL MANAGEMENT

**595.414 Project Management in an Earned Value Environment**

This course is intended for anyone who desires to explore project planning and control in more detail and how to improve these processes through the use of earned value, cost and schedule integration, and cost estimating. Specific topics will focus on schedule management; network logic; establishing a traceable schedule; risk assessment; the estimating process and types; earned value and measuring accomplishment; industry trends and tools; integrated baseline reviews; variance analysis; compliance, maintenance, and surveillance; handling subcontracts and procurements; and implementation of the project management process. The intended audience includes project and program managers, project technical personnel, procurement activity personnel, and the stakeholders and owners of projects.

**Prerequisites**: 595.464 Project Planning and Control; while the course is intended for a wide range of students, it is assumed that students will have a basic familiarity with the requirements and the disciplines of project management.

**Instructors**: Battista, Hunter

**595.460 Introduction to Project Management** VL

This course concentrates on the general methodology of managing a technical project from concept to operational use, with emphasis on the functions, roles, and responsibilities of the project manager. Topics include career aspects of project management; business factors affecting the project and the manager; project organization, planning, execution, and communications; the project life cycle; risk analysis; interface management; design review; design control assessment; reporting; and reaction to critical problems. Students are formed into groups, presented with a scenario that simulates the development of a high-technology system, and assigned to make decisions required of the project manager in the execution of the project. The project manager's decisions must then be effectively communicated (and perhaps defended) to a variety of audiences (represented by other students and faculty) that include top management, the customer, functional management, and members of the project team.

**Prerequisites**: An engineering, science, or mathematics degree and two years' work experience in science or engineering.

**Instructors**: Ackerman, Blank, Buchanan, Cameron, Holub, Kedia, Simpson, Tarchalski

**595.461 Technical Group Management**

This course covers the general functions and responsibilities of a technical group supervisor. Topics include functions of a technical group in an R&D or engineering organization; primary responsibilities of a group supervisor; interactions with management, support organizations, and project organizations; organization of projects in group structure; development of work costs and schedules; progress monitoring and reporting; introduction to personnel management—leadership, motivation, evaluation, and professional growth; reaction to critical problems; technical leadership; and planning for the future. Students assume the roles of technical group supervisors in a high-technology organization. They address typical problems in delegating responsibilities, staffing new projects, dealing with project managers, and handling conflicts and priorities.

**Prerequisites**: 595.460 Introduction to Project Management or the permission of the student's advisor or the course instructor. 595.461 can be taken concurrently with 595.460. In addition, an engineering, science, or mathematics degree and two years' work experience in science or engineering or permission of the program chair/vice chair.

**Instructors**: Bigelow, Bjerkaas, Fletcher, Harris, Hendricks, Horne-Jahrling, Miller, Regan, Taylor

**595.463 Technical Personnel Management**

This course reviews the problems of personnel management in a technical organization. Topics include environmental requirements for effective and innovative technical efforts, direction and motivation, leadership behavior, recruitment of technical staff, orientation and training programs, personnel placement and reassignment, assignment of work, salary administration, personnel evaluation and counseling, professional growth and promotion, technical obsolescence and retraining, equal opportunity programs, employee grievances, and handling of conflict situations. Students explore typical personnel management situations that arise in a technical organization.

**Prerequisite**: 595.461 Technical Group Management or permission of the student's advisor or the course instructor.

**Instructors**: Dever, Hendricks, Regan, Taylor

**595.464 Project Planning and Control**

This course concentrates on the exploration of the planning and control decisions required when developing a new high-technology product. Students are formed into groups and presented with a scenario that requires the development of a plan that will guide their organization through entry into a new business area. When developing the new product-offering plan, students must consider a wide variety of questions that their top management will need to have answered prior to making a decision to either accept or reject the plan. Other topics include the role of planning and control in project management; processes for responding to a request for proposal (RFP); assignments to prepare a statement of work (SOW), a work breakdown structure (WBS), and a critical path network (CPN) for the new product development plan; earned value performance measurement; analysis of project performance measures; integrated project planning; new product development considerations; enterprise information systems applications; and risk management.

**Prerequisite**: 595.460 Introduction to Project Management or the permission of the student's advisor or the course instructor

**Instructors**: Broadus, Egli, Holub, Liggett, Mallon, Shinn, Supplee, Suter, Taylor

**595.465 Communications in Technical Organizations**

This course covers problems and instruction in human communications within a technical organization. Topics include the nature of difficulties in human communications (perception and cognition, semantics, individual differences in processing information, and listening), techniques for effective oral and written communications and presentations, problems in communication between supervisors and subordinates, assignment of work, and reporting to management and sponsors. Students assume roles in various interpersonal situations, meetings, discussions, and conflicts calling for a supervisor to write letters and memoranda; they also deliver oral presentations and participate in group and one-on-one discussions.

**Prerequisite**: A working knowledge of material taught in 595.460 Introduction to Project Management and 595.461 Technical Group Management is recommended prior to taking this course.

**Instructors**: Bjerkaas, Collins, Fletcher, Horne-Jahrling, LaBatt, Supplee, Theodori

### 595.466 Financial and Contract Management

This course is an introduction to financial and contract management for technical managers. Topics include financial and management accounting (including elementary accounting principles, assets, liabilities, and stockholders' equity); direct and indirect costs, revenues, and profits; indices to financial position; use of financial reports; return on investment, net present value; internal rate of return; and financial management (including cash and funds flow statements). An introduction to the principles of contract formation is presented—highlighting the distinctive characteristics of contracting with the federal government—as well as the team concept for effective contracting and the role of the program manager as a key team member. Subcontract management, competitive negotiation techniques, contract financing, and cost reimbursement are also included. Case studies supplement theoretical discussions.

**Instructors**: Langhauser, Warner, Wyant

### 595.467 Principles of Agile Methods in Project Management

This course reviews both the challenges and the benefits of applying agile methods of project management in organizations. The course will use the textbook Project Management: the Agile Way by John C. Goodpasture, reprints of relevant articles and papers, and recorded video material. Topics will include fundamentals of agile; the agile business case; quality assurance; test-driven development; how scope and requirements are emergent rather than specified; time boxes are the building blocks of schedules; estimating for outcomes rather than activities; teams are performance units; governance in the agile space; earned value means delivering value; agile can be contracted and scaled; and realizing the benefits of agile.

Students are formed into groups and presented with a scenario that requires developing a plan guiding their organization to expand from employing only traditional project execution methods, which emphasize structured planning and disciplined project execution, to include the relatively recent advent of a broad portfolio of project management constructs called agile methods. As students develop this agile methods plan, they must consider a wide variety of questions their top management need answered prior to deciding whether to accept or reject the plan.

**Prerequisite**: 595.460 Introduction to Project Management

**Instructors**: Blank, Cameron

**Offered**: Fall

### 595.468 Fundamentals of Technical Innovation in Organizations

This course is designed to take graduate students majoring primarily in technical disciplines through the fundamental aspects of managing technical innovations in organizations. It will draw on interdisciplinary concepts from the technical and managerial fields of study and will specifically focus on how technical innovation management drives the long-term competitiveness of organizations operating in the global socioeconomic environment. One of the major objectives of this course is to help students understand various fundamental frameworks for managing technical resources, technical capabilities, and technical competencies for growth and renewal of their enterprises. Students will learn the basics of knowledge management, intellectual property rights, and the product-process life cycle vis-à-vis international trade patterns.

**Instructor**: Swann

### 595.731 Business Law for Technical Professionals

This course addresses legal issues commonly encountered by technical professionals, best practices in identifying and mitigating legal risks, as well as strategies to avoid costly legal errors and to recognize when professional legal advice is necessary. The course will acquaint students with various areas of the law that can interact to affect a single business transaction and will provide students with legal reasoning skills that can be applied in a technical business environment. Topics include the legal environment of business, contract basics, effective contract negotiations, breach of contract and remedies, intellectual property rights, licensing and technology transfer, protecting confidential and proprietary business information, employment law, Internet law, corporate policies, business ethics, export control regulations, and an overview of the American court system.

**Instructor**: Alavi-Hantman

### 595.740 Assuring Success of Aerospace Programs

Technical managers, systems engineers, lead engineers, and mission assurance professionals will benefit from this course, which focuses on the leadership of system safety and mission assurance activities throughout the life cycle of a project to achieve mission success. This advanced course provides crucial lessons learned and proven best practices that technical managers need to know to be successful. The integrated application of mission assurance and system engineering principles and techniques is presented in the context of aerospace programs and is also applicable to other advanced technology research and development programs. Students discuss critical risk-based decision making required from system concept definition and degree auditing through design, procurement, manufacturing, integration and test, launch, and mission operations. Shared experiences by senior aerospace leaders and extensive case studies of actual mishaps explore quality management topics relevant to aircraft, missiles, launch vehicles, satellites, and space vehicles. The course addresses contemporary leadership themes, government policies, and aerospace industry trends in mission assurance requirements, organizational structure, knowledge sharing and communication, independent review, audit, and assessment. Mission assurance disciplines covered include risk management, system safety, reliability engineering, software assurance, supply chain management, parts and materials, configuration management, requirements verification and validation, non-conformance, and anomaly tracking and trending.

**Instructors**: Day, Dever

### 595.742 Foundations of Quality Management

This course addresses quality management topics and applications vital to steering leadership and business process approaches for various organizations. Course discussions range from the history and development of modern quality programs to the latest in quality and business management, strategic planning, productivity improvement tools, techniques, and the implementation of quality initiatives needed to be successful in today's highly dynamic and competitive global market. Advanced topics related to the principles and application of quality methodologies are presented such as the impact of leadership and corporate culture on quality and the importance of quality during the proposal and contract review process. Students will understand the elements and implementation strategies of quality assurance tools and systems, including benchmarking, process control, quality measurement, supplier quality management, and auditing. Current applications and strategies for implementing effective quality management are introduced including lean manufacturing philosophies, Deming's PDCA cycle, Kaizen continuous improvement processes, and risk management. The course also covers a comprehensive and practical understanding of the implementation of quality management systems such as ISO 9001. As a result of the significant impact that software and system safety now have on today's organizations, sessions dedicated to both topics are also included.

**Instructors**: Mitchell, Seifert

### 595.762 Management of Technical Organizations

This course reviews challenges in the management of high-technology organizations at the senior technical management level. Topics include management of change and managing managers; establishing organization, technical, and business objectives and strategies; market analysis, technology, and product development; planning and costing; staffing and training to meet new needs; managing independent research and development; organizational conflicts; technical, financial, and personnel problems; and interaction with top management, staff executives, peers, and subordinates. Students assume the roles of senior technical managers dealing with typical problems in a department, including applied research, product development, and engineering support in an environment of rapidly changing technology.

**Course Note**: A working knowledge of material taught in 595.460 Introduction to Project Management, 595.463 Technical Personnel Management, 595.464 Project Planning and Control, 595.465 Communications in Technical Organizations, and 595.466 Financial and Contract Management is recommended prior to taking this course.

**Instructors**: Harris, Michelson

### 595.763 Software Engineering Management

This course covers the activities, methods, and processes needed to manage software engineering and software development projects using current best practices. Course material highlights the differences and the similarities in managing software versus hardware projects. Topics include definition and description of project framework activities and umbrella activities; estimating technical resources, project schedules, and cost; fundamentals in tracking the project using earned value measurement; approaches to building quality, maintainability, security, and other desirable characteristics into the system from the beginning; communicating with teams and customers; and CMMI and ISO. Students will develop a management plan for a project.

**Prerequisites**: 645.462 Introduction to Systems Engineering or permission of the student's advisor or the course instructor. Completion of 595.460 Introduction to Project Management is helpful. Students may not take this course if they have taken 645.764 Software Systems Engineering.

**Course Note**: This course is not available to Systems Engineering students.

**Instructors**: Battista, Caruso, Hopkins, Johnson

### 595.766 Advanced Technology VL

This course emphasizes the impact of recent technological advances on new products, processes, and needs, as well as the role of the technical manager in rapidly evolving technologies. Subject areas and lecture content track current topics of interest, such as trends and developments in microelectronics, communications, computers, intelligent machines, and expert systems. Advanced technologies in application areas such as transportation, space, manufacturing, and biomedicine are also discussed. Students are encouraged to explore new technology areas and share information with each other. The seminar format encourages student participation that culminates in a term paper on a new or emerging technology area.

**Prerequisites**: 595.460 Introduction to Project Management or 645.462 Introduction to Systems Engineering, and 595.468 Fundamentals of Technical Innovation in Organizations; or permission of the student's advisor and the course instructor.

**Instructors**: Fidler, McLoughlin, Seifert, Strawser, Suter, Theodori

### 595.781 Executive Technical Leadership VL

This course explores the roles and responsibilities of executive technical leaders within the context of a strategic framework. Examples of technical executive positions are VP/Director of R&D or Engineering, VP/Director of Manufacturing, Chief Technical Officer (CTO), Chief Information Officer (CIO), Technical Director (Government), and large program Chief Engineer.

The course introduces topics relevant to technical executives, from technical strategy development, to tactical operations such as metrics and measurements for leading technical teams within the context of larger organizations. The concepts in the course are reinforced using associated case studies, a team project, and are further fortified by practicing or retired technical executive guest interviews delivering practical career experiences related to the topics presented in the course.

The format of this course is very different from other Engineering or Technical Management courses. Lectures are offered asynchronous online with a required weekly seminar-type virtual-live discussion.

Student participation in the weekly seminar-type virtual live sessions, mid-course team presentation, semester-end capstone presentation, and executive round table is required. Students will be evaluated on their application of the principles presented in the course, critical thinking applied to the issues posed in the case study, and teamwork as assessed by both the instructors and their peer students.

**Prerequisites**: Admittance to the Engineering Management program or permission from the program chair. A working knowledge of material taught in 595.460 Introduction to Project Management, 595.463 Technical Personal Management, 595.465 Communications in Technical Organizations, and 595.466 Financial and Contract Management is recommended prior to taking this course.

**Course Notes**: The course also includes one Saturday session at JHU campus facilities in the Baltimore, MD area at the end of the semester. In person participation is preferred, with a virtual-live attendee option. The Saturday session consists of student teams presenting their capstone technical executive strategic issues, actions, and execution plan built around the case study evolution throughout the course. A practicing executive round table discussion will also be held where students have the opportunity to ask probing questions.

**Instructors**: Beaty, Blank, McLoughlin, Tarchalski (lead)

### 595.792 Management of Innovation

A critical issue for entrepreneurs and technical managers is how to translate opportunity into competitive advantage. This course explores the management of innovation, including the technical transition of applied R&D into products, the planning and launching of new products, and product management. Management of discontinuous technologies will be explored. The impact of competition by the introduction of new discontinuous technology will be addressed. Managing engineers through the creative process, as well as innovation and technological evolution, will be covered. The course includes both formal and guest lectures. Case studies will be used as an important learning vehicle.

**Instructor**: Husick

### 595.802 Directed Studies in Technical Management

In this course, qualified students are permitted to investigate possible research fields or to pursue problems of interest through reading or non-laboratory study under the direction of faculty members.

**Prerequisite**: The Independent Study/Project Form (ep.jhu.edu/student-services/academic-services/student-forms) must be completed and approved prior to registration.

**Course Note**: This course is open only to candidates in the Master of Science in Technical Management program.

**Instructors**: Goldfinger, Happel, Husick, Jacobovitz, Suter

# COMPUTER SCIENCE

### 605.101 Introduction to Python

Not for a letter grade. Offered pass/fail only. This is a six week course. The withdrawal deadline is the end of the fourth week. Students must pass each module to pass the course.

**Course Note**: Not for graduate credit.

**Instructor**: Non-facilitated

### 605.201 Introduction to Programming Using Java

This course enables students without a background in software development to become proficient programmers who are prepared for a follow-on course in data structures. The Java language will be used to introduce foundations of structured, procedural, and object-oriented programming. Topics include I/O, data types, operators, operands, expressions, conditional statements, iteration, recursion, arrays, functions, parameter passing, and returning values. Students will also be introduced to classes, objects, object references, inheritance, polymorphism, and exception handling. Additional topics include file I/O, searching, sorting, Java collections, and an introduction to applets. Students will complete several programming assignments to develop their problem-solving skills and to gain experience in detecting and correcting software errors.

**Prerequisite**: One year of college mathematics.

**Course Note**: Not for graduate credit.

**Instructors**: Deal, DeMasco, Ferguson, Qie, Smith

### 605.202 Data Structures

This course investigates abstract data types (ADTs), recursion, algorithms for searching and sorting, and basic algorithm analysis. ADTs to be covered include lists, stacks, queues, priority queues, trees, sets, and dictionaries. The emphasis is on the trade-offs associated with implementing alternative data structures for these ADTs. There will be four or five substantial Java programming assignments.

**Prerequisite**: One year of college mathematics; 605.201 Introduction to Programming Using Java or equivalent.

**Course Note**: Not for graduate credit.

**Instructors**: Chlan, Kann, Resch

### 605.203 Discrete Mathematics

This course emphasizes the relationships between certain mathematical structures and various topics in computer science. Topics include set theory, graphs and trees, algorithms, propositional calculus, logic and induction, functions, relational algebra, and matrix algebra.

**Prerequisite**: Calculus is recommended. A mathematics course beyond one year of calculus is needed for admission to the Computer Science program, students who lack this prerequisite can fulfill admission requirements by completing this course with a grade of A or B.

**Course Note**: Not for graduate credit.

**Instructor**: Chlan

### 605.204 Computer Organization

This course examines how a computer operates at the machine level. Students will develop an understanding of the hardware/software interface by studying the design and operation of computing system components. In addition, students will program at the assembly language level to understand internal system functionality. Finally, students will become familiar with the machine representations of programs and data, as well as the influence of the underlying hardware system on the design of systems software such as operating systems, compilers, assemblers, and linkers and loaders.

**Prerequisite**: 605.202 Data Structures is recommended.

**Course Note**: Not for graduate credit.

**Instructors**: Kann, Malcom, Schappelle, Snyder

### 605.205 Molecular Biology for Computer Scientists

This course is designed for students who seek to take bioinformatics courses but lack prerequisites in the biological sciences. The course covers essential aspects of biochemistry, cell biology, and molecular biology. Topics include the chemical foundations of life; cell organization and function; the structure and function of macromolecules; gene expression–transcription, translation, and regulation; biomembranes and transmembrane transport; metabolism and cellular energetics; and signal transduction. The application of foundational concepts in developmental biology, neurobiology, immunology, and cancer biology is also introduced.

**Course Note**: Not for graduate credit.

**Instructor**: Kumar

### 605.401 Foundations of Software Engineering

Fundamental software engineering techniques and methodologies commonly used during software development are studied. Topics include various life cycle models, project planning and estimation, requirements analysis, program design, construction, testing, maintenance and implementation, software measurement, and software quality. Emphasized are structured and object-oriented analysis and design techniques, use of process and data models, modular principles of software design, and a systematic approach to testing and debugging. The importance of problem specification, programming style, periodic reviews, documentation, thorough testing, and ease of maintenance are covered.

**Instructors**: Coffman, Ligozio, Lindberg, Schappelle, Wichmann

### 605.402 Secure Software Analysis and Design 🔀

This course prepares students to successfully engineer secure software systems by addressing critical security challenges across the entire software development lifecycle. Students will learn the practical skills for building secure software from the ground up through hands-on labs and exercises. Key topical areas addressed include security in software requirements, design, and development. Common security pitfalls are highlighted and examined as well as the tools and techniques for identifying and eliminating the security vulnerabilities. Security considerations in Mobile code development are also addressed. Parameterized refinement methods and transduction techniques based on mathematical based proofs are presented as a means of verifying the correctness of code and modifications to code as well as to validate conformance with functional requirements. Software protection techniques such as code obfuscation and water-marking are explored.

**Instructor**: Olagbemiro

### 605.404 Object-Oriented Programming with C++ 🔀

This course provides in-depth coverage of object-oriented programming principles and techniques using C++. Topics include classes, overloading, data abstraction, information hiding, encapsulation, inheritance, polymorphism, file processing, templates, exceptions, container classes, and low-level language features. The course briefly covers the mapping of UML design to C++ implementation and object-oriented considerations for software design and reuse. The course also relates C++ to GUI, databases, and real-time programming. The course material embraces the C++11 language standard with numerous examples demonstrating the benefits of C++11.

**Prerequisite**: Knowledge of Java or C++.

**Instructors**: Demasco, Ferguson, Pierson

### 605.405 Conceptual Design for High-Performance Systems 🏛

Recent data indicate that eighty percent of all new products or services in the United States fail within six months or fall significantly short of forecasted success. In the software industry, the average failure rate can be even higher, often entailing massive losses for both the developer, due to disappointing sales or excessive maintenance costs, and the user, due to learning difficulties and other performance systems. This course analyzes a set of issues critical to conceiving and executing a successful software product, with emphasis on complex dynamic applications. Topics are focused on three generic issues: (1) how to collect, organize, and formulate requirements encompassing both software and user performance; (2) how to define product–user interactions and design interfaces to satisfy performance requirements; and (3) how to assess the extent of requirements satisfaction (usability testing and analysis). In complex dynamic applications, user performance is particularly sensitive to design shortcomings. Discussion of such applications will concentrate on models of situation comprehension, image understanding, decision making under uncertainty, and other aspects of user performance that need to be considered to recognize and avoid typical design errors.

**Instructor**: Yufik

### 605.407 Agile Software Development Methods 🔀

This course emphasizes the quick realization of system value through disciplined, iterative, and incremental software development techniques and the elimination of wasteful practices. Students will study the full spectrum of agile methods, including Scrum, extreme programming, lean, Crystal methods, dynamic systems development method, feature-driven development, and Kanban. These methods promote teamwork, rich concise communication, and the frequent delivery of running, tested systems containing the highest-priority customer features. Agile methods are contrasted with common workplace practices and traditional methods such as Waterfall, CMMI, PMI/PMBOK, and RUP. Examples of agile adoption in industry are discussed. Additional subthemes in the course will include team dynamics, collaboration, software quality, and metrics for reporting progress.

**Instructors**: Menner

### 605.408 Software Project Management 🔀

This course describes the key aspects of a software project. It begins with the job description of a software manager and then addresses those topics germane to successful software development management, including organizing the software development team; interfacing with other engineering organizations (systems engineering, quality assurance, configuration management, and test engineering); assessing development standards; selecting the best approach and tailoring the process model; estimating software cost and schedule; planning and documenting the plan; staffing the effort; managing software cost and schedule during development; risk engineering; and continuous process improvement. Personnel management topics, including performance evaluations, merit planning, skills building, and team building, are also covered. This course introduces software engineers aspiring to become technical team leaders or software project managers to the responsibilities of these roles. For those engineers who have advanced to a software development leadership position, this course offers formal training in software project management.

**Prerequisite**: Three to five years' technical work experience is recommended.

**Instructors**: Bowers, Winston

### 605.411 Foundations of Computer Architecture

This course provides a detailed examination of the internal structure and operation of modern computer systems. Each of the major system components is investigated, including the following topics: the design and operation of the ALU, FPU, and CPU; microprogrammed vs. hardwired control, pipelining, and RISC vs. CISC machines; the memory system including caches and virtual memory; parallel and vector processing, multiprocessor systems and interconnection networks; superscalar and super-pipelined designs; and bus structures and the details of low-level I/O operation using interrupt mechanisms, device controllers, and DMA. The impact of each of these topics on system performance is also discussed. The instruction set architectures and hardware system architectures of different machines are examined and compared. The classical Von Neumann architecture is also compared and contrasted with alternative approaches such as data flow machines and neural networks.

**Instructors**: Kann, Malcom, Resch, Snyder, Whisnant

### 605.412 Operating Systems

The theory and concepts related to operating system design are presented from both developer and user perspectives. Core concepts covered include process management, memory management, file systems, I/O system management including device drivers, distributed systems, and multiuser concepts including protection and security. Process management discussions focus on threads, scheduling, and synchronization. Memory management topics include paging, segmentation, and virtual memory. Students will examine how these concepts are realized in several current open-source operating systems, including Linux. Students will complete several assignments that require the design and implementation of operating system programs using a high-level language.

**Instructors**: Deal, Noble

### 605.414 System Development in the UNIX Environment

This course describes how to implement software systems in a UNIX (POSIX-compliant) operating system environment. Students will discuss and learn the complexities, methodologies, and tools in the development of large systems that contain multiple programs. Topics include an overview of the UNIX system and its general-purpose tools, advanced makefile usage, UNIX system calls, UNIX process management, threads, and basic and advanced interprocess communication. Additional topics include source code configuration control, Perl, and debugging techniques.

**Prerequisites**: Familiarity with UNIX, experience with C++ or C.

**Instructors**: Barrett, Ching, Noble

### 605.415 Compiler Design

This course explores the principles, algorithms, and data structures involved in the design and construction of compilers. Topics include finite-state machines, lexical analysis, context-free grammars, push-down parsers, LR and LALR parsers, other parsing techniques, symbol tables, error recovery, and an introduction to intermediate code generation. Students are provided a skeleton of a functioning compiler in C to which they can add functionality. Several skeletal implementations in C++ as well as a back-end interface to Jasmin are also available. As Jasmin assembles to Java Byte Code, students can develop compilers that target any platform with a Java Virtual Machine, and by the end of the course, students will have developed a compiler for a subset of C.

**Instructor**: Ferguson

### 605.416 Multiprocessor Architecture and Programming

This course addresses how to utilize the increasing hardware capabilities of multiprocessor computer architecture's high-performance computing platforms for software development. The famous Moore's Law is still alive, although it is now realized from increasing the number of CPU cores instead of increasing CPU clock speed. This course describes the differences between single-core and multi-core systems and addresses the impact of these differences in multiprocessor computer architectures and operating systems. Parallel programming techniques to increase program performance by leveraging the multiprocessor system, including multi-core architectures, will be introduced. Additional topics include program performance analysis and tuning, task parallelism, synchronization strategies, shared memory access and data structures, and task partition techniques. The course encourages hands-on experience with projects selected by the student.

**Instructor**: Zheng

**605.417 Introduction to GPU Programming** 🏛

This course will teach the fundamentals needed to utilize the ever-increasing power of the GPUs housed in the video cards attached to our computers. For years, this capability was limited to the processing of graphics data for presentation to the user. With the CUDA and OpenCL frameworks, programmers can develop applications that harness this power directly to search, modify, and quickly analyze large amounts of various types of data. Students will be introduced to core concurrent programming principles, along with the specific hardware and software considerations of these frameworks. In addition, students will learn canonical algorithms used to perform high-precision mathematics and data transformations. Class time will be split between lectures and hands-on exercises. There will be two individual projects in both CUDA and OpenCL programming, which will allow students to independently choose demonstrable goals, develop software to achieve those goals, and present the results of their efforts.

**Instructor**: Pascale

**605.420 Algorithms for Bioinformatics** 🔀

This follow-on course to data structures (e.g., 605.202 Data Structures) provides a survey of computer algorithms, examines fundamental techniques in algorithm design and analysis, and develops problem-solving skills required in all programs of study involving computer science. Topics include advanced data structures (red-black and 2-3-4 trees, union-find), algorithm analysis and computational complexity (recurrence relations, big-O notation, introduction to NP-completeness), sorting and searching, design paradigms (divide and conquer, greedy heuristic, dynamic programming), and graph algorithms (depth-first and breadth-first search, minimum spanning trees). Advanced topics are selected from among the following: multi-threaded algorithms, matrix operations, linear programming, string matching, computational geometry, and approximation algorithms. The course will draw on applications from Bioinformatics.

**Prerequisite**: 605.202 Data Structures or equivalent.

**Course Notes**: This course does not satisfy the foundation course requirement for Computer Science or Cybersecurity. Students cannot earn credit for both 605.420 and 605.421.

**Instructor**: Chlan

**605.421 Foundations of Algorithms** 🔀

This follow-on course to data structures (e.g., 605.202) provides a survey of computer algorithms, examines fundamental techniques in algorithm design and analysis, and develops problem-solving skills required in all programs of study involving computer science. Topics include advanced data structures (red-black and 2-3-4 trees, union-find), recursion and mathematical induction, algorithm analysis and computational complexity (recurrence relations, big-O notation, NP-completeness), sorting and searching, design paradigms (divide and conquer, greedy heuristic, dynamic programming, amortized analysis), and graph algorithms (depth-first and breadth-first search, connectivity, minimum spanning trees, network flow). Advanced topics are selected from among the following: randomized algorithms, information retrieval, string and pattern matching, and computational geometry.

**Prerequisites**: 605.202 Data Structures or equivalent. 605.203 Discrete Mathematics or equivalent is recommended.

**Instructors**: Lew, Maurer, Rodriguez, Sadowsky, Sheppard

**605.422 Computational Signal Processing** 🏛

This course introduces computational aspects of signal processing, specifically algorithms for processing digital signals, methods for the design and analysis of signal processing algorithms, architectures for signal processing systems, and areas of application. Topics include signal analysis (signal definition, time and frequency domains, sampling and digitizing, noise and error), systems for signal processing (filters and non-filters, correlation, adaptation), and algorithms and architectures (fast Fourier transforms, fast convolution, digital filtering, interpolation and resampling, digital signal processors, function evaluation, and computational complexity). Areas of application include communication systems, speech signal processing, and digital media.

**Prerequisites**: Knowledge of complex numbers and linear algebra.

**Instructors**: Marks, Sadowsky

**605.423 Applied Combinatorics and Discrete Mathematics** 🏛

Combinatorics and discrete mathematics are becoming increasingly important fields of mathematics because of their extensive applications in computer science, statistics, operations research, and engineering. The purpose of this course is to teach students to model, analyze, and solve combinatorial and discrete mathematical problems. Topics include elements of graph theory, the pigeonhole principle, counting methods, generating functions, recurrence relations and their solution, and the inclusion-exclusion formula. Emphasis is on the application of the methods to problem solving.

**Course Note**: This course is the same as 625.417 Applied Combinatorics and Discrete Mathematics.

**Instructor**: Whisnant

### 605.424 Logic: Systems, Semantics, and Models

The use of predicate logic for modeling information systems is widespread and growing. Knowledge representation, for example, has long been important in artificial intelligence applications and is now emerging as a critical component of semantic web applications. Similarly, predicate logic is the basis for ontologies and inferential knowledge bases. This course teaches the fundamentals of propositional and predicate logic, with an emphasis on semantics. Modal logic is introduced as a tool to manage non-truth functional systems, and dynamic logic is introduced to manage potentially inconsistent systems, such as may arise in merging disparate databases or in combining diagnostic models of related systems.

**Course Note**: This course may be counted toward a three-course track in Database Systems and Knowledge Management.
**Instructor**: Waddell

### 605.425 Probabilistic Graphical Models

This course introduces the fundamentals behind the mathematical and logical framework of graphical models. These models are used in many areas of machine learning and arise in numerous challenging and intriguing problems in data analysis, mathematics, and computer science. For example, the "big data" world frequently uses graphical models to solve problems. While the framework introduced in this course will be largely mathematical, we will also present algorithms and connections to problem domains. The course will begin with the fundamentals of probability theory and will then move into Bayesian networks, undirected graphical models, template-based models, and Gaussian networks. The nature of inference and learning on the graphical structures will be covered, with explorations of complexity, conditioning, clique trees, and optimization. The course will use weekly problem sets and a term project to encourage mastery of the fundamentals of this emerging area.

**Prerequisites**: Graduate course in probability and statistics (such as 625.403 Statistical Methods of Data Analysis).

**Course Note**: This course is the same as 625.492 Probabilistic Graphical Models.

**Instructor**: Woolf

### 605.426 Image Processing

Fundamentals of image processing are covered, with an emphasis on digital techniques. Topics include digitization, enhancement, segmentation, the Fourier transform, filtering, restoration, reconstruction from projections, and image analysis including computer vision. Concepts are illustrated by laboratory sessions in which these techniques are applied to practical situations, including examples from biomedical image processing.

**Prerequisite**: Familiarity with Fourier transforms.

**Instructor**: Rodriguez and Walton

### 605.427 Computational Photography

Computational photography is an emerging research area at the intersection of computer graphics, image processing, and computer vision. As digital cameras become more popular and collections of images continue to grow, we have seen a surge in interest in effective ways to enhance photography and produce more realistic images through the use of computational techniques. Computational photography overcomes the limitations of conventional photography by analyzing, manipulating, combining, searching, and synthesizing images to produce more compelling, rich, and vivid visual representations of the world. This course will introduce the fundamental concepts of image processing, computer vision, and computer graphics, as well as their applications to photography. Topics include image formation, filtering, blending, and completion techniques. In addition, the course will discuss different image analysis and rendering techniques including texture analysis, morphing, and non-photorealistic rendering.

**Instructor**: Caban

### 605.428 Applied Topology

The course is both an introduction to topology and an investigation of various applications of topology in science and engineering. Topology, simply put, is a mathematical study of shapes, and it often turns out that just knowing a rough shape of an object (whether that object is as concrete as platonic solids or as abstract as the space of all paths in large complex networks) can enhance one's understanding of the object. We will start with a few key theoretical concepts from point-set topology with proofs, while letting breadth take precedence over depth, and then introduce key concepts from algebraic topology, which attempts to use algebraic concepts, mostly group theory, to develop ideas of homotopy, homology, and cohomology, which render topology "computable." Finally, we discuss a few key examples of real-world applications of computational topology, an emerging field devoted to the study of efficient algorithms for topological problems, especially those arising in science and engineering, which builds on classical results from algebraic topology as well as algorithmic tools from computational geometry and other areas of computer science. The questions we like to ask are: Do I know the topology of my network? What is a rough shape of the large data set that I am working with (is there a logical gap?) Will the local picture of a part of the sensor field I am looking at give rise to a consistent global common picture?

**Prerequisites**: Multivariate calculus, linear algebra and matrix theory (e.g., 625.409 Matrix Theory), and an undergraduate-level course in probability and statistics.

**Course Note**: This course is the same as 625.487 Applied Topology.

**Instructor**: Chin

**605.429 Programming Languages** 🏛
This course compares and contrasts a wide variety of features of at least twelve programming languages, including programming language history; formal methods of describing syntax and semantics; names, binding, type checking, and scopes; data types; expressions and assignment statements; statement-level control structures; design and implementation of subprograms; exception handling; and support for object oriented programming. Students will also learn and write four-week projects in three programming languages (e.g., Python, Perl, and C#).
**Instructor**: Mauer

**605.451 Principles of Cloud Computing** 🔀
Cloud computing helps organizations realize cost savings and efficiencies without spending capital resources up front, while modernizing and expanding their IT capabilities. Cloud-based infrastructure is rapidly scalable, secure, and accessible over the Internet—you pay only for what you use. So, enterprises worldwide, big and small, are moving towards cloud-computing solutions for meeting their computing needs, including the use of Infrastructure as a Service (IasS) and Platform as a Service (PaaS). We have also seen a fundamental shift from shrink-wrapped software to Software as a Service (SaaS) in data centers across the globe. Moreover, providers such as Amazon, Google, and Microsoft have opened their datacenters to third parties by providing low-level services such as storage, computation, and bandwidth. This trend is creating the need for a new kind of enterprise architect, developer, QA, and operational professional—someone who understands and can effectively use cloud-computing technologies and solutions. In this course, we discuss critical cloud topics such as cloud service models (IaaS, PaaS SaaS), virtualization and how it relates to cloud, elastic computing, cloud storage, cloud networking, cloud databases, cloud security and architecting developing and deploying apps in the cloud. The format of this course will be a mix of lectures, and hands-on demos. Upon completing this course, students will have a deeper understanding of what cloud computing is and the various technologies that make up cloud computing, along with hands-on experience working with a major cloud provider.
**Instructors**: Joshi, Shyamsundar

**605.432 Graph Analytics** 🏛
Graphs are a flexible data structure that facilitate fusion of disparate data sets. Applications of graphs have shown steady growth with the development of internet, cyber, and social networks, presenting large graphs for which analysis remains a challenging problem. This course introduces algorithms and techniques to address large scale graph analytics. It will blend graph analytics theory, hands on development of graph analytics algorithms, as well as processing approaches that support the analytics. We will start by introducing graphs, their properties, and example applications, including necessary background on probability & linear algebra. Statistical properties of random and scale free graphs will be introduced. Graph analytic methods, including centrality measures, graph partitioning, HITS algorithms, connected components, cliques, trusses, and graph clustering, will be followed by dynamic graph processes such as diffusion, contagion, opinion formation and collaboration. Students will use standard Graph interfaces as well as linear algebra based methods to analyze graphs. Distributed graph storage, query, and processing approaches that support graph analytics will be discussed. Students will identify and apply suitable algorithms and analysis techniques to a variety of graph analytics problems, as well as gain experience setting up and solving these problems. There will be hands on programming assignments.
**Instructor**: Savkli

**605.433 Social Media Analytics** 🏛
Today an immense social media landscape is being fueled by new applications, growth of devices (e.g., smart phones and devices), and human appetite for online engagement. With a myriad of applications and users, significant interest exists in the obvious question, "How does one better understand human behavior in these communities to improve the design and monitoring of these communities?" To address this question a multi-disciplinary approach that combines social network analysis (SNA), natural language processing, and data analytics is required. This course combines all these topics to address contemporary topics such as marketing, population influence, etc. There will be several small projects.
**Prerequisite**: Knowledge of Python or R.
**Instructor**: McCulloh and Piorkowski

**605.441 Principles of Database Systems** 🔀
This course examines the underlying concepts and theory of database management systems. Topics include database system architectures, data models, query languages, conceptual and logical database design, physical organization, and transaction management. The entity-relationship model and relational model are investigated in detail, object-oriented databases are introduced, and legacy systems based on the network and hierarchical models are briefly described. Mappings from the conceptual level to the logical level, integrity constraints, dependencies, and normalization are studied as a basis for formal design. Theoretical languages such as the relational

algebra and the relational calculus are described, and high-level languages such as SQL and QBE are discussed. An overview of file organization and access methods is provided as a basis for discussion of heuristic query optimization techniques. Finally, transaction processing techniques are presented with a specific emphasis on concurrency control and database recovery.

**Instructors**: Kann, Kung, Liu

### 605.443 The Semantic Web

The Semantic Web is an activity by the WWW Consortium to create a large set of XML-based languages, along with information on how various tags relate to real-world objects and concepts. This course covers Semantic Web technologies, including RDF (Resource Description Format, a structure for describing and interchanging metadata on the web) and OWL (Web Ontology Language), with domain-specific standards and ontologies (formal specifications of how to represent objects and concepts). Representative applications of RDF, OWL, and ontologies will be discussed. Students will complete a Semantic Web project in an application area of interest to them. Examples will be drawn from several application areas.

**Prerequisite**: 605.444 XML Design Paradigms or equivalent.

**Course Note**: This course may be counted toward a three-course track in Bioinformatics.

**Instructor**: Cost

### 605.444 XML Design Paradigms

The course explores understanding the trade-offs among XML grammars and XML techniques to solve different classes of systems. Topics include optimization of XML grammars for different XML technologies; benefits of using different XML schema languages; trade-offs in using different parsing approaches; benefits of parsing technology vs. XML query; the role of Web 2.0 to deliver functionality through various web services approaches; exploiting XML to drive audio, visual, and tactile displays; the role of XML in multiplying the power of standard web browser technologies; and the role of Web 3.0 to deliver Semantic Web functionality. XML technologies that will be covered include XML Schema, XPath, XSLT, SAX, DOM, XQuery, SOAP, WSDL, JAX-B, JAXWS, REST, RDF, and OWL.

**Prerequisite**: 605.481 Principles of Enterprise Web Development or equivalent Java experience.

**Course Note**: Formerly 635.444 XML: Technology and Applications.

**Instructors**: Chittargi, Silberberg

### 605.445 Artificial Intelligence

The incorporation of advanced techniques in reasoning and problem solving into modern, complex systems has become pervasive. Often, these techniques fall within the realm of artificial intelligence. This course focuses on artificial intelligence from an agent perspective and explores issues of knowledge representation and reasoning. Students will participate in lectures and discussions on various topics, including heuristic and stochastic search, logical and probabilistic reasoning, planning, learning, and perception. Advanced topics will be selected from areas such as robotics, vision, natural language processing, and philosophy of mind. Students will complete problem sets and small software projects to gain hands-on experience with the techniques and issues covered.

**Instructor**: Butcher

### 605.446 Natural Language Processing

This course introduces the fundamental concepts and techniques of natural language processing (NLP). Students will gain an in-depth understanding of the computational properties of natural languages and the commonly used algorithms for processing linguistic information. The course examines NLP models and algorithms using both the traditional symbolic and the more recent statistical approaches. It includes treatment of natural languages at the lexical, syntactic, semantic, and pragmatic levels. The course also covers the development of modern NLP systems using statistical and machine learning techniques.

**Prerequisite**: 605.445 Artificial Intelligence or equivalent.

**Instructor**: Kumar

### 605.447 Neural Networks

This course provides an introduction to concepts in neural networks and connectionist models. Topics include parallel distributed processing, learning algorithms, and applications. Specific networks discussed include Hopfield networks, bidirectional associative memories, perceptrons, feedforward networks with back propagation, and competitive learning networks, including self-organizing and Grossberg networks. Software for some networks is provided.

**Prerequisite**: Multivariate calculus and linear algebra.

**Course Note**: This course is the same as 625.438 Neural Networks.

**Instructor**: Fleischer

### 605.448 Data Science

This course will cover the core concepts and skills in the emerging field of data science. The data science pipeline will be explored in depth: problem formulation, the acquisition and cleaning of multisource data sets, data summarization and exploratory analysis, model building, analysis and evaluation, and the presentation of results. Topics covered will include types of data sources and databases, web scraping and APIs, text parsing and regular expressions, experimental design, summary statistics, data visualizations, supervised (regression, logistic regression, decision trees, random forests, etc.) and unsupervised (clustering, network analysis) machine learning techniques, model evaluation and testing, and the construction of web applications and reports to present results. Students will gain direct experience in solving the programming and analytical challenges associated with data science through short assignments and a larger project.

**Prerequisite**: Programming experience in Python is recommended.

**Instructor**: Butcher

### 605.451 Principles of Bioinformatics 🔀

This course is an interdisciplinary introduction to computational methods used to solve important problems in DNA and protein sequence analysis. The course focuses on algorithms but includes material to provide the necessary biological background for science and engineering students. Algorithms to be covered include dynamic programming for sequence alignment, such as Smith– Waterman, FASTA, and BLAST; hidden Markov models, such as the forward, Viterbi, and expectation maximization algorithms; a range of gene-finding algorithms; phylogenic tree construction; and clustering algorithms.

**Prerequisites**: Familiarity with probability and statistics; working knowledge of Java, C++, or C; 605.205 Molecular Biology for Computer Scientists or a course in molecular biology; and either a course in cell biology or biochemistry.

**Instructor**: Qie

### 605.452 Biological Databases and Database Tools 🔀

The sequencing of the human genome and intense interest in proteomics and molecular structure have resulted in an explosive need for biological databases. This course surveys a wide range of biological databases and their access tools and enables students to develop proficiency in their use. Databases introduced include genome and sequence databases such as GenBank and Ensemble, as well as protein databases such as PDB and SWISS-PROT. Tools for accessing and manipulating sequence databases such as BLAST, multiple alignment, Perl, and gene finding tools are covered. Specialized databases such as KEGG and HapMap are surveyed for their design and use. The course also focuses on the design of biological databases and examines issues related to heterogeneity, interoperability, complex data structures, object orientation, and tool integration. Students will create their own small database as a course project and will complete homework assignments using biological databases and database tools.

**Prerequisites**: 605.205 Molecular Biology for Computer Scientists or equivalent; 605.441 Principles of Database Systems or 410.634 Practical Computer Concepts for Bioinformatics recommended.

**Instructor**: Hobbs

### 605.453 Computational Genomics 🔀

This course focuses on current problems of computational genomics. Students will explore bioinformatics software, discuss bioinformatics research, and learn the principles underlying a variety of bioinformatics algorithms. The emphasis is on algorithms that use probabilistic and statistical approaches. Topics include analyzing eukaryotic, bacterial, and viral genes and genomes, genome sequencing and assembling, finding genes in genomes and identifying their biological functions, predicting regulatory sites, and assessing gene and genome evolution.

**Prerequisite**: 605.205 Molecular Biology for Computer Scientists or equivalent and familiarity with probability and statistics.

**Instructor**: Ermolaeva

### 605.456 Computational Drug Discovery and Development 🔀

Recent advances in bioinformatics and drug discovery platforms have brought us significantly closer to the realization of rational drug design and development. Across the pharmaceutical industry, considerable effort is being invested in developing experimental and translational medicine, and it is starting to make a significant impact on the drug discovery process itself. This course examines the major steps of the evolving modern drug discovery platforms, the computational techniques and tools used during each step of rational drug discovery, and how these techniques facilitate the integration of experimental and translational medicine with the discovery/development platforms. The course will build on concepts from a number of areas including bioinformatics, computational genomic/proteomics, in silico system biology, computational medicinal chemistry, and pharmaceutical biotechnology. Topics covered in the course include comparative pharmacogenomics, protein/antibody modeling, interaction and regulatory networks, QSAR/pharmacophores, ADME/toxicology, and clinical biomarkers. Relevant mathematical concepts are developed as needed in the course.

**Prerequisite**: 605.205 Molecular Biology for Computer Scientists or equivalent.

**Instructor**: Kumar

**605.457 Statistics for Bioinformatics**

This course provides an introduction into the statistical methods commonly used in bioinformatics and biological research. The course briefly reviews basic probability and statistics including events, conditional probabilities, Bayes' theorem, random variables, probability distributions and hypothesis testing and then proceeds to topics more specific to bioinformatics research, including Markov chains, hidden Markov models, Bayesian statistics and Bayesian networks. Students will learn the principles behind these statistical methods and how they can be applied to analyze biological sequences and data.

**Prerequisite**: 605.205 Molecular Biology for Computer Scientists or equivalent, and 410.645 Biostatistics or another statistics course.

**Instructor**: Ermaloeva

**605.462 Data Visualization**

This course explores the underlying theory and practical concepts in creating visual representations of large amounts of data. It covers the core topics in data visualization: data representation, visualization toolkits, scientific visualization, medical visualization, information visualization, flow visualization, and volume rendering techniques. The related topics of applied human perception and advanced display devices are also introduced.

**Prerequisite**: Experience with data collection/analysis in data-intensive fields or background in computer graphics (e.g., 605.467 Computer Graphics ) is recommended.

**Instructor**: Chlan

**605.467 Computer Graphics**

This course examines the principles of computer graphics, with a focus on the mathematics and theory behind 2D and 3D graphics rendering. Topics include graphics display devices, graphics primitives, 2D and 3D transformations, viewing and projection, color theory, visible surface detection and hidden surface removal, lighting and shading, and object definition and storage methods. Practical application of these concepts is emphasized through laboratory exercises and code examples. Laboratory exercises use the C++ programming language and OpenGL on a PC.

**Prerequisite**: Familiarity with linear algebra.

**Instructor**: Nesbitt

**605.471 Principles of Data Communications Networks**

This course provides an introduction to the field of data communications and computer networks. The course covers the principles of data communications, the fundamentals of signaling, basic transmission concepts, transmission media, circuit control, line sharing techniques, physical and data link layer protocols, error detection and correction, data compression, network security techniques, common carrier services and data networks, and the mathematical techniques used for network design and performance analysis. Potential topics include analog and digital signaling; data encoding and modulation; Shannon channel capacity; FDM, TDM, and STDM multiplexing techniques; inverse multiplexing; analog and digital transmission; PCM encoding and T1 transmission circuits; CRC error detection and Hamming and Viterbi error correction techniques; Huffman and Lempel–Ziv data compression algorithms; symmetric key and public key encryption, authentication and digital signatures, PKI and key distribution, secure e-mail and PGP; circuit, packet, and cell switching techniques; TCP/IP protocols and local area networks; network topology optimization algorithms, reliability and availability, and queuing analysis; and circuit costing.

**Instructors**: Boules, Nieporent, Smith

**605.472 Computer Network Architectures and Protocols**

This course provides a detailed examination of the conceptual framework for modeling communications between processes residing on independent hosts, as well as the rules and procedures that mediate the exchange of information between two communication processes. The Open Systems Interconnection Reference Model (OSIRM) is presented and compared with TCP/IP and other network architectures. The service definitions and protocols for implementing each of the seven layers of the reference model using both OSI and TCP/IP protocols are analyzed in detail. Internetworking among heterogeneous subnets is described in terms of addressing and routing, and techniques for identifying different protocol suites sent over the subnets are explained. The protocol header encoding rules are examined, and techniques for parsing protocol headers are analyzed. The application layer sub-architecture for providing common application services is described, and interoperability techniques for implementing multiprotocol Internets are presented. Topics include layering, encapsulation, SAPs, and PDUs; sliding window protocols, flow and error control; virtual circuits and datagrams; routing and congestion control algorithms; internetworking; NSAP and IP addressing schemes; CLNP, IPv4, and the new IPv6 Internet protocols; RIP, OSPF, ES-IS, and IS-IS routing protocols; TP4 and TCP transport protocols; dialog control, activity management, and the session layer protocol; ASN.1 encoding rules and the presentation layer protocol; application layer structure and the ACSE, CCR, ROSE, and RTSE common application service elements; OSI VT, FTAM, and MOTIS application protocols; TCP/

IP TELNET, FTP, and SMTP application protocols; OSI transitioning tools; multiprotocol networks; and encapsulation, tunneling, and convergence techniques.

**Prerequisite**: 605.471 Principles of Data Communications Networks.

**Instructor**: Nieporent

### 605.473 High-Speed Networking Technologies

The Internet has experienced an unprecedented growth especially since the 1990s and is continuing to evolve in terms of the information transfer speeds and infrastructure capacities in order to accommodate the growing number of users. The demand for both wired and wireless bandwidth, and innovative new bandwidth-intensive services is soaring. The use of high-definition video, real-time collaboration, e-commerce, social networking and other multimedia Web applications is becoming increasingly important to individual users and businesses. The use of mobile broadband and file sharing applications is rising sharply. Advances in research applications and the evolution to Cloud networking are also causing bandwidth pressure on existing networks.

This course will provide an in-depth understanding of the Internet architecture and underlying technologies and applications that address the challenges summarized above and provide services to users at high-availability, reliability, and flexibility in a cost effective manner. Specific topics to be discussed in this course include high-speed Internet requirements analysis, Internet architecture and protocols, convergence of mobile and terrestrial networks, high-speed LAN/WAN options and configurations, emerging and future switching and transmission technologies, and network virtualization. The course will also cover unique challenges to management and security of the high-speed Internets and how they are addressed, emerging technologies, and future trends.

**Prerequisite**: 605.471 Principles of Data Communications Networks.

**Course Note**: Formerly 605.773 High-Speed Networking Technologies.

**Instructor**: Krishnan

### 605.474 Network Programming

Emphasis is placed on the theory and practice associated with the implementation and use of the most common process-to-process communications associated with UNIX. The inter-process communications comprise both local and distributed architectures. The distributed communications protocols include those most widely implemented and used: the worldwide Internet protocol suite [the Transmission Control Protocol/ Internet Protocol (TCP/ IP), and the US government-mandated International Organization for Standardization (ISO) protocol suite]. Practical skills are developed, including the ability to implement and configure protocol servers (daemons) and their clients. Students are expected to have working knowledge of UNIX.

**Prerequisite**: 605.471 Principles of Data Communications Networks or 605.414 System Development in the UNIX Environment.

**Course Note**: Formerly 605.774 Network Programming

**Instructor**: Noble

### 605.475 Protocol Design and Simulation

This course covers the formal design, specification, and validation of computer and network protocols. Design, implementation, and verification of protocols will be illustrated using the latest simulation tools, such as OPNET and NS2. Protocol examples include the latest wired and wireless networks, such as the IEEE 802.X family, as well as protocols in VoIP, Web 2.0, and network security. The course focuses on protocol specification, structured protocol design, protocol models, and protocol validation. Students will gain hands-on experience using simulation tools to design, validate, and assess protocols.

**Prerequisite**: 605.471 Principles of Data Communications Networks or equivalent.

**Instructor**: Zheng

### 605.477 Internetworking with TCP/IP I

This course investigates the underlying technology of the Internet. The presentation begins with a survey of distributed applications operating over the Internet, including the web, electronic mail, VoIP, instant messaging, file transfers, and peer-to-peer file sharing. The course investigates the details of the Internet architecture and the TCP/IP protocol suite, covering the protocols that provide communications services to end systems and the management and control protocols that create the Internet from disparate underlying networks and technologies. Communications-related protocols analyzed in detail include the foundational Internet Protocol (IP), the connection-oriented reliable Transmission Control Protocol (TCP), the connectionless User Datagram Protocol (UDP), and the Real-Time Protocol (RTP) for streaming media. To allow the student to understand the control and management of the Internet, the course analyzes protocols that support naming (DNS); addressing and configuration (DHCP); management (SNMP); and the dynamic IP routing protocols RIP, OSPF, and BGP.

**Prerequisite**: 605.471 Principles of Data Communications Networks.

**Instructors**: Boudra, DeSimone, Scott

### 605.478 Cellular Communications Systems

This course introduces the principles of cellular communications systems. Second-generation (2G) digital, mobile cellular, and personal communications systems (PCS) concepts are discussed, including the cellular concept, frequency reuse, propagation, multiple access, power control, handoff, and traffic engineering. Limitations of 2G cellular systems are described, and improvements proposed by 2.5G and 3G cellular standards to support high-rate data services are presented. Emphasis is placed on layer 2 and above, such as retransmission protocols, medium access control, call processing, interworking, radio resource management (e.g., frequency, time, and power), QoS provisioning, scheduling, and mobility management (e.g., mobile IP). The Wireless Local Area Networking IEEE 802.11 WLAN, the Wireless Metropolitan Area Networking IEEE 802.16 (Fixed and Mobile) WiMAX, and Wireless Personal Area Networking IEEE 802.15 Bluetooth are discussed for their roles in 3G. The Media Independent Handover standard IEEE 802.21 (e.g., integrating WLAN and 3G cellular networks to provide session/service continuity) is also introduced. Cellular standards are examined, including US 2G code-division multiple access (CDMA) IS-95A, 2.5G IS-95B, 3G cdma2000 1x, and 1x-EVDO. Other standards discussed include European 2G time-division multiple access (TDMA) Global System for Mobile communication (GSM), 2.5G General Packet Radio Service (GPRS), 2.5G Enhanced Data Rates for GSM Evolution (EDGE), 3G wideband-CDMA (W-CDMA), and 4G Long Term Evolution (LTE).

**Prerequisite**: 605.471 Principles of Data Communications Networks.

**Instructors**: Mishra, Shyy

### 605.481 Principles of Enterprise Web Development

This course examines three major topics in the development of applications for the World Wide Web. The first is website development using HTML and related standards. The second is the implementation of client-side applications using the Java programming language, including user interface development, asynchronous event handling, multithreaded programming, and network programming. Distributed object protocols via RMI or CORBA and distributed database access via JDBC may also be introduced. The third topic is the design of server-side web applications, for which students will examine the underlying web protocol (HTTP), the development of client-side interfaces (e.g., via HTML forms), and the implementation of server-side programs (e.g., via Java servlets or traditional CGI).

**Instructors**: Evans, Spiegel

### 605.484 Agile Development with Ruby on Rails

Modern web applications are expected to facilitate collaboration, with user participation being a significant facet of the system. Components such as wikis, blogs, and forums are now commonplace. While feature sets continue to expand, there is continuing pressure to develop and deploy capabilities more quickly to enable organizations to remain competitive. This pressure has led to the development of languages and frameworks geared toward rapid prototyping, with Ruby on Rails being the most popular. Ruby on Rails is a model-view-controller (MVC) framework that enables efficient application development and deployment. Techniques such as convention over configuration and object-relational mapping with ActiveRecord along with enhanced AJAX support offer a simple environment with significant productivity gains. This code-intensive course introduces Ruby on Rails, the patterns it implements, and its applicability to the rapid development of collaborative applications.

**Prerequisite**: 605.481 Principles of Enterprise Web Development or equivalent.

**Instructor**: Hazins

### 605.486 Mobile Application Development for the Android Platform

This project-oriented course will investigate the issues surrounding application development for mobile platforms. First, we will look at techniques for building applications that adapt to the ways in which mobile apps differ from traditional desktop or web-based apps: constrained resources, small screen sizes, varying display resolutions, intermittent network connectivity, specialized sensors, security restrictions, and so forth. Second, we will look at best practices for making mobile applications flexible: using XML-based layouts, managing multimedia, storing user data, networking via NFC and WiFi, determining device location and orientation, deploying applications, and gracefully handling shutdowns and restarts to the application. We will also explore embedding web components in applications, showing maps with the Google Maps plug-in, and storing local data with SQLite.

**Prerequisite**: 605.481 Principles of Enterprise Web Development or equivalent Java experience.

**Course Notes**: Students will be provided links to download free tools for building and testing Android apps; Android devices are required for online sections of this course. The instructor has a limited number of loaner devices for in-person sections.

**Instructor**: Stanchfield

### 605.701 Software Systems Engineering

Software systems engineering applies engineering principles and the system view to the software development process. The course focuses on the engineering of complex systems that have a strong software component. This course is based on the philosophy that the key to engineering a good software system lies just as much in the process that is followed as in the purely technical regime. The course will show how good a software development process is and how to make a software process better by studying successful techniques that have been employed to produce correct software systems within budget. Topics are explored in a sequence designed to reflect the way one would choose to implement process improvements. These topics include steps to initiate process change, methods to establish control over the software process, ways to specify the development process, methods for quantitative process control, and how to focus on problem prevention. Students will prepare term projects.

**Prerequisite**: One software engineering course beyond 605.401 Foundations of Software Engineering.

**Instructors**: Donaldson, Siegel

### 605.702 Service-Oriented Architecture

Service-Oriented Architecture (SOA) is a way to organize and use distributed capabilities that may be controlled by different owners. SOA provides a uniform means to offer, discover, interact with, and use capabilities to produce desired effects consistent with specified preconditions and requirements. This course describes SOA concepts and design principles, interoperability standards, security considerations, runtime infrastructure, and web services as an implementation technology for SOA. Given the focus on shared capabilities, SOA involves more than technology. Therefore, additional topics will include the impact of SOA on culture, organization, and governance.

**Prerequisites**: 605.401 Foundations of Software Engineering and 605.704 Object-Oriented Analysis and Design or equivalent experience are highly recommended.

**Instructors**: Earle, Pole

### 605.704 Object-Oriented Analysis and Design

This course describes fundamental principles of object-oriented modeling, requirements development, analysis, and design. Topics include specification of software requirements; object-oriented analysis approaches, including dynamic and static modeling with the Unified Modeling Language (UML v2); object-oriented design; object-oriented reuse, including design patterns; and software implementation concerns. Optional topics include the Systems Modeling Language (SysML), Object-Oriented Systems Engineering Methodology (OOSEM), managing object-oriented projects, and the Object Constraint Language (OCL).

**Prerequisite**: Experience in object-oriented programming using a language such as Java or C++.

**Instructors**: Demasco, Pierson, Schappelle, Schepers

### 605.705 Software Safety

This course describes how to develop and use software that is free of imperfections that could cause unsafe conditions in safetycritical systems. Systems engineering and software engineering techniques are described for developing "safeware," and case studies are presented regarding catastrophic situations that resulted from software and system faults that could have been avoided. Specific techniques of risk analysis, hazard analysis, fault tolerance, and safety trade-offs within the software engineering paradigm are discussed.

**Instructor**: Gieszl

### 605.707 Design Patterns

Software patterns encapsulate the knowledge of experienced software professionals in a manner that allows developers to apply that knowledge to similar problems. Patterns for software are analogous to the books of solutions that enable electrical engineers and civil engineers to avoid having to derive every new circuit or bridge design from first principles. This course will introduce the concept of software patterns and explore the wide variety of patterns that may be applied to the production, analysis, design, implementation, and maintenance of software. The format of the course will emphasize the discussion of patterns and their application. Each student will be expected to lead a discussion and to actively participate in others. Students will also be expected to introduce new patterns or pattern languages through research or developed from their own experience. Programming exercises performed outside of class will be used enhance discussion and illustrate the application of patterns.

**Prerequisite**: 605.404 Object-Oriented Programming with C++ or permission of instructor.

**Instructors**: Lindberg, Stanchfield

### 605.708 Tools and Techniques of Software Project Management

This course examines tools and techniques used to lead software-intensive programs. Techniques for RFP analysis and proposal development are explored, and techniques of size estimation (function points, feature points, and lines-of-code estimation) and the use of models such as COCOMO to convert size to effort and schedule are described. In addition, conversion of estimated effort to dollars and the effects of fringe, overhead, skill mix profiles, and staffing profiles on total dollar cost are explained. Moreover, techniques for estimating effort and planning COTS intensive development programs are described, and tools and techniques for measuring process maturity and process efficiency (e.g., CMMi, Lean, Six Sigma, and Kaizen) are addressed. The course also investigates the formation and management of virtual teams, as well as techniques that can be used to ensure success in this environment. Finally, the course addresses topics that require collaboration between the project manager and human resources, such as personnel retention strategies, managing unsatisfactory performance, and formal mentoring programs.

**Prerequisite**: Three to five years' technical work experience is recommended.

**Instructors**: Bowers, Winston

### 605.709 Seminar in Software Engineering

This course examines the underlying concepts and latest topics in software engineering. Potential topics include use of effective open-source software development techniques such as agile methods, automated code generation, testing strategies, development tools and environments, patterns, metrics in the development process, successful teamwork, and training aspects of CMMI. Each student will select and report on a software engineering topic, independently research a topic, and prepare a paper describing a major software engineering issue. The course is taught using a seminar format in which significant portions of the class period are set aside for students to lead and actively participate in discussions.

**Prerequisite**: One software engineering course beyond 605.401 Foundations of Software Engineering or permission of the instructor.

**Instructor**: Pole

### 605.713 Robotics

This course introduces the fundamentals of robot design and development, with an emphasis on autonomy. Robot design, navigation, obstacle avoidance, and artificial intelligence will be discussed. Topics covered in robot design include robot structure, kinematics and dynamics, the mathematics of robot control (multiple coordinate systems and transformations), and designing for autonomy. Navigation topics include path planning, position estimation, sensors (e.g., vision, ultrasonics, and lasers), and sensor fusion. Obstacle avoidance topics include obstacle characterization, object detection, sensors, and sensor fusion. Topics to be discussed in artificial intelligence include learning, reasoning, and decision making. Students will deepen their understanding through several assignments and the term-long robot development project.

**Instructor**: Lapin

### 605.715 Software Development for Real-Time Embedded Systems

This course examines the hardware and software technologies behind real-time, embedded computer systems. From smart kitchen appliances to sophisticated flight control for airliners, embedded computers play an important role in our everyday lives. Hardware topics include microcomputers and support devices (e.g., flash, ROM, DMA, timers, clocks, A/D, and D/A), as well as common applications (e.g., servo and stepper motor control, automotive sensors, and voice processing). Software topics focus on unique aspects of embedded programming and include interrupts, real-time control, communication, common design patterns, and special test considerations. The course also explores the unique tools that are used to develop and test embedded systems. Several labs using a popular robotics development system and Java reinforce the concepts presented.

**Prerequisite**: Programming experience with Java.

**Instructor**: Ferguson

### 605.716 Modeling and Simulation of Complex Systems

This course focuses on the application of modeling and simulation principles to complex systems. A complex system is a large-scale nonlinear system consisting of interconnected or interwoven parts (such as a biological cell, the economy, or an ecological system). The course begins with an overview of complex systems, followed by modeling and simulation techniques based on nonlinear differential equations, networks, stochastic models, cellular automata, and swarm-like systems. Existing software systems will be used to illustrate systems and provide practical experience. During the semester, each student will complete a modeling project of a complex system. While this course is intended for computer science or engineering students interested in modeling any complex system, it may also be taken by bioinformatics students interested in modeling complex biological systems. Students interested in bioinformatics will study a parallel track exposing them to existing whole-cell modeling tools such as E-Cell, COPASI, and BioSpice.

**Prerequisites**: Knowledge of elementary probability and statistics and previous exposure to differential equations. Students applying this course to the Master of Science in Bioinformatics should also have completed at least one Bioinformatics course prior to enrollment.

**Course Note**: This course may be counted toward a three-course track in Bioinformatics.

**Instructor**: Weisman

### 605.721 Design and Analysis of Algorithms

In this follow-on course to 605.421 Foundations of Algorithms, design paradigms are explored in greater depth, and more advanced techniques for solving computational problems are presented. Topics include randomized algorithms, adaptive algorithms (genetic, neural networks, simulated annealing), approximate algorithms, advanced data structures, online algorithms, computational complexity classes and intractability, formal proofs of correctness, sorting networks, and parallel algorithms. Students will read research papers in the field of algorithms and will investigate the practicality and implementation issues with state-of-the-art solutions to algorithmic problems. Grading is based on problem sets, programming projects, and in-class presentations.

**Prerequisites**: 605.421 Foundations of Algorithms or equivalent; 605.203 Discrete Mathematics or equivalent.

**Instructor**: Boon

### 605.722 Computational Complexity 🏛

Computational complexity theory is concerned with the intrinsic complexity of computational tasks, asking what can be achieved with limited computational resources. This course provides an introduction to complexity theory, emphasizing the implications of theoretic results for applications in computer science. In doing so, it comes to grips with questions such as the following: Is it easier to verify a proposed solution to a problem than it is to find a solution? Is it easier to find an approximate solution than an exact solution? Are randomized algorithms more powerful than deterministic algorithms? Are quantum computers more powerful than classical computers? In studying the progress that has been made to answer questions such as these, we will develop insights into the nature of computation and the implications of complexity theory for the practical development of algorithms. Specific topics include the P vs. NP problem (why is this problem so fundamental, and why is it so hard to solve?); approximation algorithms for NP-hard optimization problems; the limits of approximability; randomized algorithms, interactive proofs, and pseudorandomness; complexity and cryptography; and quantum complexity. All background in theoretical computer science is developed as needed in the course.

**Prerequisite**: 605.421 Foundations of Algorithms or equivalent.

**Instructor**: Faculty

### 605.725 Queuing Theory with Applications to Computer Science 🏛

Queues are a ubiquitous part of everyday life; common examples are supermarket checkout stations, help desk call centers, manufacturing assembly lines, wireless communication networks, and multitasking computers. Queuing theory provides a rich and useful set of mathematical models for the analysis and design of service process for which there is contention for shared resources. This course explores both theory and application of fundamental and advanced models in this field. Fundamental models include single- and multiple-server Markov queues, bulk arrival and bulk service processes, and priority queues. Applications emphasize communication networks and computer operations but may include examples from transportation, manufacturing, and the service industry. Advanced topics may vary.

**Prerequisites**: Multivariate calculus and a graduate course in probability and statistics such as 625.403 Statistical Methods and Data Analysis or equivalent.

**Course Note**: This course is the same as 625.734 Queuing Theory with Applications to Computer Science.

**Instructor**: Nickel

### 605.726 Game Theory 🏛

Game theory is a field of applied mathematics that describes and analyzes interactive decision making when two or more parties are involved. Since finding a firm mathematical footing in 1928, it has been applied to many fields, including economics, political science, foreign policy, and engineering. This course will serve both as an introduction to and a survey of applications of game theory. Therefore, after covering the mathematical foundational work with some measure of mathematical rigor, we will examine many real-world situations, both historical and current. Topics include two-person/N-person game, cooperative/noncooperative game, static/dynamic game, and combinatorial/strategic/coalitional game, as well as their respective examples and applications. Further attention will be given to the meaning and the computational complexity of finding of Nash equilibrium.

**Prerequisites**: Multivariate calculus, linear algebra and matrix theory (e.g., 625.409 Matrix Theory), and a course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis).

**Course Note**: This course is the same as 625.741 Game Theory.

**Instructor**: Henry

### 605.727 Computational Geometry 🏛

This course covers fundamental algorithms for efficiently solving geometric problems, especially ones involving 2D polygons and 3D polyhedrons. Topics include elementary geometric operations; polygon visibility, triangulation, and partitioning; computing convex hulls; Voronoi diagrams and Delaunay triangulations with applications; special polygon and polyhedron algorithms such as point containment and extreme point determination; point location in a planar graph subdivision; and robot motion planning around polygon obstacles. The course covers theory to the extent that it aids in understanding how the algorithms work. Emphasis is placed on implementation, and programming projects are an important part of the course work.

**Prerequisite**: Familiarity with linear algebra.

**Instructor**: Boon

### 605.728 Quantum Computation

Polynomial-time quantum algorithms, which exploit nonclassical phenomena such as superposition and entanglement, have been developed for problems for which no efficient classical algorithm is known. The discovery of these fast quantum algorithms has given rise to the field of quantum computation, an emerging research area at the intersection of computer science, physics, and mathematics. This course provides an introduction to quantum computation for computer scientists. Familiarity with quantum mechanics is not a prerequisite. Instead, relevant aspects of the quantum mechanics formalism will be developed in class. The course begins with a discussion of the quantum mechanics formalism and relevant ideas from (classical) computational complexity. It then develops the idea of a quantum computer. This discussion provides the basis for a detailed examination of Shor's polynomial-time algorithm for integer factorization and Grover's search algorithm. The course concludes with a discussion of quantum cryptography. Required work will include problem sets and a research project.

**Prerequisite**: Some familiarity with linear algebra and with the design and analysis of algorithms.

**Instructor**: Zaret

### 605.729 Formal Verification

Formal verification of a program is the mathematical proof that the program does what is expected. The 21st century has seen a vast worldwide interest in formal methods. Four journals (Automated Reasoning, Logic and Algebraic Programming, Formalized Mathematics, and Science of Computer Programming) and over a dozen yearly conferences are specifically devoted to this subject. Formal methods have been developed for Java (JML), Ada (SPARC), C#, C, and Eiffel (Spec#), Haskell, Ocaml, and Scheme (Coq), Pascal (Sunrise), Modula-3 (ESC), and a number of special-purpose languages. This course introduces this vast world of formal methods. Our concern will be the formal verification of the widest possible variety of programming language features and techniques. Each student will carry out an investigation of one or another of the existing formal verification systems, applying it to a program of the student's choice.

**Instructor**: Mauer

### 605.741 Large-Scale Database Systems

This course investigates the theory and practice of modern large-scale database systems. Large-scale approaches include distributed relational databases; data warehouses; and the Hadoop ecosystem (Hadoop, Accumulo, and the Mahout machine learning libraries). Topics discussed include data design and architecture; database security, integrity, query processing, query optimization, transaction management, concurrency control, and fault tolerance; and query formulation, algorithms, and cloud analytics. . At the end of the course, students will understand the principles of several common large-scale data systems including their architecture, performance, and costs. Students will also gain a sense of which approach is recommended for different circumstances.

**Prerequisite**: 605.441 Principles of Database Systems or equivalent. Familiarity with "big-O" concepts and notation is recommended.

**Course Note**: Formerly 605.741 Distributed Database Systems: Cloud Computing and Data Warehouses.

**Instructor**: Silberberg

### 605.744 Information Retrieval

A multi-billion-dollar industry has grown to address the problem of finding information. Commercial search engines are based on information retrieval: the efficient storage, organization, and retrieval of text. This course covers both the theory and practice of text retrieval technology. Topics include automatic index construction, formal models of retrieval, Internet search, text classification, multilingual retrieval, question answering, and related topics in NLP and computational linguistics. A practical approach is emphasized, and students will complete several programming projects to implement components of a retrieval engine. Students will also give a class presentation based on an independent project or a research topic from the information retrieval literature.

**Instructors**: McNamee, Navarro

### 605.745 Reasoning Under Uncertainty

This course is concerned with the problems of inference and decision making under uncertainty. It develops the theoretical basis for a number of different approaches and explores sample applications. The course discusses foundational issues in probability and statistics, including the meaning of probability statement, and the necessity of a rational agent acting in accord with probability theory. We will look at possible generalizations of Bayesian probability, including Dempster–Shafer theory. Next, we will develop algorithms for Bayesian networks—graphical probabilistic models—for exact and approximate inference and consider several application areas. Finally, the course will examine the problem of making optimal decisions under uncertainty. We will explore the conceptual foundations of decision theory and then consider influence diagrams, which are graphical models extending Bayesian networks to the domain of decision analysis. As time permits, we will also look at Bayesian games and Markov decision processes. Pertinent background in probability and theoretical computer science is developed as needed in the course.

**Instructor**: Watkins

### 605.746 Machine Learning

How can machines improve with experience? How can they discover new knowledge from a variety of data sources? What computational issues must be addressed to succeed? These are questions that are addressed in this course. Topics range from determining appropriate data representation and models for learning, understanding different algorithms for knowledge and model discovery, and using sound theoretical and experimental techniques in assessing performance. Specific approaches covered include statistical techniques (e.g., k-nearest neighbor and Bayesian learning), logical techniques (e.g., decision tree and rule induction), function approximation (e.g., neural networks and kernel methods), and reinforcement learning. The topics are discussed in the context of current machine learning and data mining research. Students will participate in seminar discussions and will complete and present the results of an individual project.

**Prerequisite**: 605.445 Artificial Intelligence is recommended but not required.

**Instructor**: Sheppard

### 605.747 Evolutionary Computation

Recently, principles from the biological sciences have motivated the study of alternative computational models and approaches to problem solving. This course explores how principles from theories of evolution and natural selection can be used to construct machines that exhibit nontrivial behavior. In particular, the course covers techniques from genetic algorithms, genetic programming, and artificial life for developing software agents capable of solving problems as individuals and as members of a larger community of agents. Specific topics addressed include representation and schemata; selection, reproduction, and recombination; theoretical models of evolutionary computation; optimal allocation of trials (i.e., bandit problems); search, optimization, and machine learning; evolution of programs; population dynamics; and emergent behavior. Students will participate in seminar discussions and will complete and present the results of an individual project.

**Prerequisite**: 605.445 Artificial Intelligence is recommended but not required.

**Instructor**: Sheppard

### 605.748 Semantic Natural Language Processing

This course introduces the fundamental concepts underlying knowledge representation, semantics, and pragmatics in natural language processing. Students will gain an in-depth understanding of the techniques central to computational semantics and discourse for processing linguistic information. The course examines semantic NLP models and algorithms using both the traditional symbolic and the more recent statistical approaches. The course also covers the development of modern NLP systems capable of carrying out dialogue and conversation.

**Prerequisite**: 605.445 Artificial Intelligence or equivalent

**Course Note**: This course and 605.446 Natural Language Processing can be taken independently of each other.

**Instructor**: Kumar

### 605.751 Computational Aspects of Molecular Structure

This course focuses on computational methods for studying protein and RNA structure, protein-protein interactions, and biological networks. Algorithms for prediction of RNA secondary structure, protein–protein interactions, and annotation of protein secondary/tertiary structure and function are studied in depth. Students will apply various computer programs and structure-visualization software to secondary and tertiary protein structure prediction, structure–structure comparison, protein domain classification, annotation of functionally important sites, and protein design. Interesting aspects of protein interaction and metabolic networks are also discussed.

**Prerequisites**: 605.205 Molecular Biology for Computer Scientists or equivalent. 605.451 Principles of Computational Biology is recommended.

**Instructor**: Qie

### 605.754 Analysis of Gene Expression and High-Content Biological Data

The development of microarray technology, rapid sequencing, protein chips, and metabolic data has led to an explosion in the collection of "high-content" biological data. This course explores the analysis and mining of gene expression data and high-content biological data. A survey of gene and protein arrays, laboratory information management systems, data normalization, and available tools is followed by a more in-depth treatment of differential gene expression detection, clustering techniques, pathway extraction, network model building, biomarker evaluation, and model identification. Both clinical and research data will be considered. The student will develop skills in statistical analysis and data mining, including statistical detection theory, nonlinear and multiple regression, entropy measurement, detection of hidden patterns in data, and heuristic search and learning algorithms. Applied mathematical concepts and biological principles will be introduced, and students will focus on algorithm design and software application for designing and implementing novel ways of analyzing gene, protein, and metabolic expression data. The statistical programming language R is used extensively in lecture and homework. Packages from Bioconductor, including many that contain data sets, are used regularly as well. Students will complete data analysis assignments individually and in small teams.

**Prerequisites**: 605.205 Molecular Biology for Computer Scientists or equivalent or a prior course in Bioinformatics, a course in probability and statistics, and ability to program in a high-level language.

**Course Notes**: There are no exams, but programming assignments are intensive. Students in the Master of Science in Bioinformatics program may take both this course and 410.671 Microarrays & Analysis, as the content is largely mutually exclusive.

**Instructor**: Boon

### 605.755 Systems Biology

During the last decade, systems biology has emerged as an effective tool for investigation of complex biological problems, placing emphasis on the analysis of large-scale data sets and quantitative treatment of experimental results. In this course, students will explore recent advances in systems biology analysis of intracellular processes. Examples of modeling and experimental studies of metabolic, genetic, signal transduction, and cell cycle regulation networks will be studied in detail. The classes will alternate between consideration of network-driven and network element (gene, metabolite, or protein)-driven approaches. Students will learn to use Boolean, differential equations, and stochastic methods of analysis and will become acquainted with several powerful experimental techniques, including basics of microfabrication and microfluidics. For their course projects, students will develop models of a signal transduction or metabolic pathway.

**Prerequisites**: Courses in molecular biology (605.205 Molecular Biology for Computer Scientists or 410.602 Molecular Biology) and differential equations.

**Instructor**: Kumar

### 605.759 Independent Project in Bioinformatics

This course is for students who would like to carry out a significant project in bioinformatics as part of their graduate program. The course may be used to conduct minor research, an in-depth literature survey, or a software implementation related to recent developments in the field. Students who enroll in this course are encouraged to attend at least one industry conference in bioinformatics that is related to their area of study. To enroll in this course, the student must be within two courses of degree completion and must obtain the approval and support of a sponsoring faculty member.

**Course Note**: A student may not receive credit for both 605.759 and 605.802 Independent Study in Computer Science II.

**Instructor**: Faculty

### 605.767 Applied Computer Graphics

This course examines advanced rendering topics in computer graphics. The course focuses on the mathematics and theory behind 3D graphics rendering. Topics include 3D surface representations including fractal geometry methods; visible surface detection and hidden surface removal; and surface rendering methods with discussion of lighting models, color theory, texturing, and ray tracing. Laboratory exercises provide practical application of these concepts. The course also includes a survey of graphics rendering applications (animation, modeling and simulation, and realistic rendering) and software. Students perform laboratory exercises using the C++ programming language.

**Prerequisite**: 605.467 Computer Graphics or familiarity with three-dimensional viewing and modeling transformations.

**Instructor**: Nesbitt

### 605.771 Wired and Wireless Local and Metropolitan Area Networks

This course provides a detailed examination of wired and wireless local and metropolitan area network (LAN and MAN) technologies, protocols, and the methods used for implementing LANand MAN-based enterprise intranets. The structure and operation of the IEEE 802 media access control (MAC) and physical layer protocols are examined in detail. The 802.2 logical link control, 802.3/Ethernet, 802.4 token bus, and the 802.5 token ring protocols are analyzed, and the construction of LAN-based enterprise intranets is examined through a detailed analysis of bridging, routing, and switching techniques. High-speed LAN technologies are discussed through an examination of FDDI, Fast Ethernet, 100VG AnyLAN, ATM LAN Emulation (LANE), and Fibre Channel protocols, along with the new standards for gigabit and 10-gigabit Ethernet. In addition, the 802.6 DQDB and 802.17 Resilient Packet Ring MAN protocols are discussed. Finally, the new and emerging wireless LAN and MAN standards are examined. The 802.11 (WiFi) wireless LAN and 802.15 (Bluetooth) wireless PAN standards are discussed in detail along with the emerging 802.16 (WiMAX) wireless MAN standard. Topics include

Manchester and Differential Manchester encoding techniques; bus, star, and ring topologies; optical fiber, coaxial cable, and UTP media; baseband, broadband, and carrierband bus networks; hubs, switched LANs, and full duplex LANs; VLANs and prioritization techniques; transparent and source routing bridge algorithms; packet bursting and carrier extension schemes; wireless spread spectrum and frequency hopping transmission techniques; wireless collision avoidance media access control; and security schemes. Students may use the network lab to configure LAN switches and Cisco routers, as well as to observe the interconnection of LAN networks.

**Prerequisite**: 605.471 Principles of Data Communications Networks.

**Instructor**: Nieporent

### 605.772 Network and Security Management

Network management encompasses all the activities, methods, operational procedures, tools, communications interfaces, protocols, and human resources that pertain to the operation, administration, maintenance, and provisioning of communications networks and plan for their growth and evolution. Security management pertains to monitoring and control of security services and mechanisms including identification, authentication, authorization, access control, confidentiality, intrusion prevention, detection, and correction in order to protect the communications network infrastructure and services. The course will cover network and security management standards, technologies, industry best practices, and case studies. Network and security management (NSM) involves setting, monitoring, and maintaining certain performance metrics to ensure high performance levels and quality of service (QoS) to the users. NSM includes support for infrastructure architecture and security planning, design, and implementation. Specific Internet and telecommunications standards discussed in depth in this course include SNMPv1, SNMPv2, SNMPv3, RMON, and TMN. Other standards covered include 3GPP/IMS, Cable, DSL, RSVP, TIA-1039, DiffServ, and InteServ. This course will also examine areas in NSM that can be automated and current issues and future trends.

**Prerequisites**: 605.771 Wired and Wireless Local and Metropolitan Area Networks, or 605.472 Computer Network Architectures and Protocols, or 605.477 Internetworking with TCP/IP I, or 635.411 Principles of Network Engineering.

**Instructor**: Krishnan

### 605.775 Optical Networking Technology

The Internet has hundreds of millions of users, is growing rapidly, and continues to evolve to accommodate an increasing number of voice, data, video, and imagery applications with diverse service requirements. Internet Protocol (IP) is the primary unifying protocol converging these applications and services over the Internet. The Internet's evolution has been accompanied by exponentially growing traffic volume on the network infrastructure. Optical networks are ideally suited to carry such large volumes of traffic, and the next generation of optical networks will be optimized for delivery of IP services while providing capacity in the range of terabits per second in a scalable and flexible way to support services such as voice over IP (VoIP) and IP television (IPTV). This course provides an in-depth understanding of existing and emerging optical network technologies. Specific topics covered include basics of fiber optic communications, SONET, DWDM, optical Ethernet, FTTB, FTTH, optical wavelength switching, IP over optical networks, MPLS, and GMPLS. Additional topics that may be discussed include optical network standards, network control and management, static and dynamic service provisioning, optical network design, and future directions.

**Prerequisite**: 605.473 High-Speed Networking Technologies or permission of the instructor.

**Instructor**: Krishnan

### 605.776 Fourth-Generation Wireless Communications: WiMAX and LTE

This course compares the WiMAX and LTE fourth-generation (4G) technologies and their performance. An overview of the IEEE 802.16 standards (802.16d/e/j/m/n/p) and WiMAX Forum (Fixed WiMAX vs. Mobile WiMAX, Interoperability certification and Core network) is presented along with the 3GPP standards for LTE and LTE-Advanced as well as LTE network architecture. The physical layer (OFDM, OFDMA, Scalable OFDMA, SCFDMA, FDD/TDD, and DL/UL channels), reference signal/ pilot, 2D resources, and multi-antenna techniques (diversity, MIMO, and beam forming) for both technologies is introduced. For WiMAX, the MAC, call flow, 2D resource map, QoS, and scheduling are presented. For LTE, both control plane and data plane protocols for Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) and Evolved Packet Core (EPC) are presented. The topics include protocol architecture, bearer management, signaling, radio resource control (RRC), packet data convergence protocol (PDCP), radio link control (RLC), and MAC. In addition, the role of universal subscriber identity module (USIM), eNodeB, mobility management entity (MME), serving gateway (S-GW), packet data network gateway (P-GW), and home subscription server (HSS), as well as the call flow across these various nodes, will be presented. The 2D resource grid along with QoS and scheduling will be explained in detail. The voice over LTE (VoLTE), self-organizing network (SON), LTE-direct, and LTE-Advanced [including coordinated multipoint (CoMP), carrier aggregation, and Intercell interference coordination (ICIC)] will be presented.

Finally, spectrum considerations as well as the concept of white space and dynamic spectrum access (DSA) will be discussed.

**Prerequisites**: 605.471 Principles of Data Communications Networks or 635.411 Principles of Network Engineering and another course in the Data Communications and Networking track.

**Instructor**: Shyy

### 605.777 Internetworking with TCP/IP II

This course builds on the foundation established in 605.477 Internetworking with TCP/IP I. Changes are being made in the infrastructure, operation, and protocols of the Internet to provide the performance and services needed for real-time applications. This course first examines the current architecture and operation of the Internet. The classful addressing concept will be introduced, and the mapping of Internet addresses to physical addresses will be discussed, along with the extensions that have been made to the addressing paradigm, including subnet addressing, classless addressing, and network address translation. The performance enhancements being developed to provide quality of service (QoS) over the Internet and to provide faster routing through the use of IP switching techniques will be discussed. Techniques for providing multicasting and mobility over the Internet will be examined. Security considerations will be addressed by examining virtual private networks and the use of IP security (IPSec) protocols. The next-generation IP protocol (IPv6) will be introduced, and the changes and enhancements to the IP protocol operation and to the addressing architecture will be discussed in detail. Finally, the development of the voice over IP (VoIP) application and the convergence of circuit switching and packet switching will be discussed. Topics include subnet addressing, CIDR, DHCP, DNS, NAT, IntServ, DiffServ, RSVP, CIP, MPOA, IP switching, tag switching, MPLS, IP multicast, IGMP, reliable multicast, multicast routing protocols, IP mobility home agents and foreign agents, message tunneling, proxy and gratuitous ARP, VPN tunneling, PPTP, L2F, L2TP and SOCKSv5, VPN security, IPSec, encapsulating security payload header, authentication header, security association, IPv6 addressing, IPv6 protocol and extension headers, neighbor discovery, IPv6 stateless address autoconfiguration, DHCPv6, VoIP, H.323 gateways and gatekeeper, SIP, SDP, RTP, MGCP, and Megaco/H.248.

**Prerequisite**: 605.477 Internetworking with TCP/IP I.

**Instructor**: Nieporent

### 605.778 Voice Over IP

The Internet has been growing exponentially and continues to evolve to accommodate an increasingly large number of applications with diverse service requirements. A remarkable aspect of this evolution is the convergence of real-time communications services with traditional data communications services over the Internet. In particular, Internet telephony, or voice over IP, is one of the most promising services currently being deployed. While there are many benefits to voice over IP, such as cost effectiveness and enhanced features, there exist a number of barriers to the widespread deployment of Internet telephony. The purpose of this course is to provide in-depth understanding of the concept and operation of voice over IP and discuss issues and strategies to address the issues. In this course, students will gain understanding of how to adapt an IP packet network, which is basically designed for data, to provide wide-area voice communications. Topics include telephony fundamentals, voice over IP concepts, adapting IP networks to support voice, H.323 and SIP signaling protocols, QoS issues in IP networks, IETF standards, and network management.

**Prerequisite**: 605.477 Internetworking with TCP/IP I or 605.473 High-Speed Networking Technologies, or significant Internet technology-related work experience.

**Instructor**: Krishnan

### 605.779 Network Design and Performance Analysis

Networking services are a staple of our daily life. Different types of networks surround us all day round. This ubiquitous networking, thanks to smartphones and tablet computers, gives us the convenience of information at our fingertips. The right network architecture provides the fundamental support for network services, such as the products from Facebook, Google, Apple, etc. This course covers the details of network design and the design process. Starting from requirement specifications, a detail flow analysis is introduced. Examples of different network architecture designs, both in wireline and wireless, will be discussed, including mobile Ad Hoc network (MANET), mesh network, 4G cellular networks, wide area network (WAN , cloud networks, and advanced software define networking (SDN). Performance analyses and network security aspects are considered at the every step of the design. Secured architecture covers Virtual Private Network (VPN) and Transport Layer Security (TLS)-based systems, with details on firewall and intrusion detection configurations. The course encourages hands-on projects selected from real network system problems

**Instructor**: Zheng

### 605.782 Web Application Development with Java

This project-oriented course will enable students to use various techniques for building browser-based applications for dynamically generated websites, e-commerce, web-enabled enterprise computing, and other applications that require web access to server-based resources. Particular attention will be paid to methods for making web-based applications efficient, maintainable, and flexible. The course will use at least two sets of tools: servlets/ JSP and a higher-level Java-based framework such as JSF 2.0. Major topics will include handling HTTP request information, generating HTTP response data, tracking sessions, designing custom tag libraries or components, page templating, asynchronous page updates with Ajax, and separating content from presentation through use of the MVC architecture. Additional topics may include HTML5, database access techniques for web apps, web app security, and dependency injection in web apps (e.g., with the Spring framework).

**Prerequisite**: 605.481 Principles of Enterprise Web Development or equivalent Java experience.

**Course Note**: Formerly 605.782 Web Application Development with Servlets and JavaServer Pages (JSP).

**Instructors**: Chaikin, Chittargi, Hall, Shyamsunder

### 605.784 Enterprise Computing with Java 🔀

This course covers enterprise computing technologies using Java Enterprise Edition (Java EE). The course describes how to build multitier distributed applications, specifically addressing web access, business logic, data access, and applications supporting enterprise service technologies. For the web access tier, the focus will be on development using servlets and JSP, with an emphasis on integrating the web tier with enterprise applications. For the business logic tier, session beans for synchronous business processing and message-driven beans and timers for asynchronous business processing will be described. The data access tier discussion will focus on Java database connectivity (JDBC), data access patterns, and the Java Persistence API. Finally, enterprise services will be discussed, including the Java Naming and Directory Interface (JNDI), the Java message service (JMS), remote method invocation (RMI), Java Transaction API (JTA), and Java EE security. Students will build applications using the technologies presented.

**Prerequisite**: 605.481 Principles of Enterprise Web Development or equivalent.

**Instructors**: Felikson, Shyamsunder, Stafford

### 605.785 Web Services with SOAP and REST: Frameworks, Processes, and Applications 🔀

Web services is a technology, process, and software paradigm to extend the web from an infrastructure that provides services for humans to one that supports business integration over the web. This course presents concepts, features, and architectural models of web services from three perspectives: framework, process, and applications. Students will study three emerging standard protocols: Simple Object Access Protocol (SOAP); Web Services Description Language (WSDL); and Universal Description, Discovery, and Integration (UDDI). In contrast, Representational State Transfer (REST) is an architectural style for designing networked applications and exposing web services. REST delivers simplicity and true interoperability and is an alternative to complex mechanism such as CORBA, RPC, or SOAP-based web services and allows using simple HTTP to make calls between machines. The course will explain the REST principles and show how to use the Java standards for developing applications using RESTful API. Students will learn the benefits of and the technical architecture for using REST in applications, including how to design, build, and test RESTful services using Java and JAX-RS. This includes the role of key technologies such as HTTP, Extensible Markup Language (XML), and JavaScript Object Notation (JSON). Students also learn how to consume RESTful services in applications, including the role of JavaScript and Ajax, and how the RESTful approach differs from the SOAP-based approach, while comparing and contrasting the two techniques. Finally, the course will review other web services specifications and standards, and it will describe the use of web services to resolve business applications integration issues. WS-I Basic Profile and other guidance documents and recommended practices will be discussed in the context of achieving high levels of web services interoperability.

**Prerequisites**: 605.444 XML Design Paradigms or equivalent XML and Java programming experience; knowledge of the J2EE platform and programming model is recommended.

**Instructor**: Felikson

### 605.786 Enterprise System Design and Implementation 🔀

This course explores enterprise architectures for the development of scalable distributed systems. Effective patterns for distributed data access, MVC-based web tiers, and business logic components are explored as students build complex applications. Factors such as caching and clustering that enable distributed systems to scale to handle potentially thousands of users are a primary focus. In addition, creating a reusable blueprint for an enterprise architecture will be discussed. Applications developed utilizing these concepts are selected from current research topics in information retrieval, data visualization, and machine learning.

**Prerequisites**: 605.784 Enterprise Computing with Java. 605.707 Design Patterns or equivalent experience is recommended.

**Instructors**: M. Cherry and P. Cherry

**605.787 Rich Internet Applications with Ajax**

Using a web browser to access online resources is convenient because it provides universal access from any computer on any operating system in any location. Unfortunately, it often results in a poor user experience because HTML is a weak and non-interactive display language and HTTP is a weak and inefficient protocol. Full-fledged browser-embedded programs (e.g., ActiveX components, Java applets) have not succeeded in penetrating the market adequately, so a new class of applications has grown up that uses only the capabilities already available in most browsers. These applications were first popularized by Google but have since exploded in popularity throughout the developer community. The techniques to implement them were based on a group of technologies collectively known as Ajax, and the resultant applications were richer than the relatively static pure-HTML-based web applications that preceded them. These applications have become known as Ajax applications, rich Internet applications, or Web 2.0 applications. This course will examine techniques to develop and deploy Ajax applications. We will look at the underlying techniques, then explore client-side tools (e.g., jQuery), server-side tools (e.g., JSON-RPC), and hybrid tools (e.g., the Google Web Toolkit) to simplify the development process. As we delve into several popular client and server-side libraries, we will be examining and paying attention to issues of usability, efficiency, security, and portability.

**Prerequisites**: 605.782 Web Application Development with Java or equivalent servlet and JSP experience.

**Instructors**: Chaikin, Hall, Shyamsunder

**605.788 Big Data Processing Using Hadoop**

Organizations today are generating massive amounts of data that are too large and too unwieldy to fit in relational databases. Therefore, organizations and enterprises are turning to massively parallel computing solutions such as Hadoop for help. The Apache Hadoop platform, with Hadoop Distributed File System (HDFS) and MapReduce (M/R) framework at its core, allows for distributed processing of large data sets across clusters of computers using the map and reduce programming model. It is designed to scale up from a single server to thousands of machines, offering local computation and storage. The Hadoop ecosystem is sizable in nature and includes many subprojects such as Hive and Pig for big data analytics, HBase for real-time access to big data, Zookeeper for distributed transaction process management, and Oozie for workflow. This course breaks down the walls of complexity of distributed processing of big data by providing a practical approach to developing applications on top of the Hadoop platform. By completing this course, students will gain an in-depth understanding of how MapReduce and Distributed File Systems work. In addition, they will be able to author Hadoop-based MapReduce applications in Java and also leverage Hadoop subprojects to build powerful data processing applications.

**Prerequisite**: 605.481 Principles of Enterprise Web Development or equivalent Java experience.

**Course Note**: This course may be counted toward a three-course track in Databases and Knowledge Management.

**Instructors**: May, Pascale, Shyamsunder

**605.801 Independent Study in Computer Science I**

This course permits graduate students in computer science to work with a faculty mentor to explore a topic in depth or conduct research in selected areas. Requirements for completion include submission of a significant paper or project.

**Prerequisites**: Seven computer science graduate courses including the foundation courses, three track-focused courses, and two courses numbered 605.7xx, or admission to the post-master's certificate. Students must also have permission of a faculty mentor, the student's academic advisor, and the program chair.

**605.802 Independent Study in Computer Science II**

Students wishing to take a second independent study in computer science should sign up for this course.

**Prerequisites**: 605.801 Independent Study in Computer Science I and permission of a faculty mentor, the student's academic advisor, and the program chair.

**Course Note**: A student may not receive credit for both 605.759 Independent Project in Bioinformatics and 605.802.

# APPLIED PHYSICS

**615.421 Electric Power Principles**

This is an introductory course on electric power, its distribution, and its applications. The first half of the course focuses on the physics of electric power and its generation, with an emphasis on distribution and distribution systems. Topics to be covered include AC voltages and currents, transmission lines, mono- and poly-phase systems, and losses due to electromagnetic forces. The second half of the course is directed toward applications. Specific applications covered include system analysis and protection, power electronics, induction and permanent magnet motors, transformers, etc. At least one lecture will be used to bring all the concepts together by studying the implementation of an alternative power generation system using wind turbines. During the course of the term, several research papers on power generation and distribution will be read and summarized by the students. A term paper on an electric power subject may be required.

**Instructor**: Faculty

### 615.441 Mathematical Methods for Physics and Engineering 🏛

This course covers a broad spectrum of mathematical techniques essential to the solution of advanced problems in physics and engineering. Topics include ordinary and partial differential equations, contour integration, tabulated integrals, saddle-point methods, linear vector spaces, boundary-value problems, eigenvalue problems, Green's functions, integral transforms, and special functions. Application of these topics to the solution of problems in physics and engineering is stressed.

**Prerequisites**: Vector analysis and ordinary differential equations (linear algebra and complex variables recommended).

**Instructor**: Adelmann

### 615.442 Electromagnetics 🏛

Maxwell's equations are derived and applied to the study of topics including electrostatics, magnetostatics, propagation of electromagnetic waves in vacuum and matter, antennas, waveguides and cavities, microwave networks, electromagnetic waves in plasmas, and electric and magnetic properties of materials.

**Prerequisites**: Knowledge of vector analysis, partial differential equations, Fourier analysis, and intermediate electromagnetics.
**Instructor**: Awadallah

### 615.444 Fundamentals of Space Systems and Subsystems I 🔀

This course is intended for the physicist or engineer interested in the design of space experiments and space systems. This class presents the fundamental technical background, current state of the art, and example applications in the development of space systems. Topics include systems engineering, space environment, astrodynamics, propulsion and launch vehicles, attitude determination and control, and space power systems. This course is team taught by experts in their respective fields.

**Prerequisites**: An undergraduate degree in physics or engineering or the equivalent.

**Course Notes**: This course may be taken for 700-level credit with the additional requirement of a research paper. See 615.744 Fundamentals of Space Systems and Subsystems I.

**Instructor**: Pisacane-Coordinator

### 615.445 Fundamentals of Space Systems and Subsystems II 🏛

This course is intended for the physicist or engineer interested in the design of space experiments and space systems. The course presents the technical background, current state of the art, and example applications in the development of space systems. Topics include spacecraft thermal control, spacecraft configuration and structural design, space communications, risk analysis, command and telemetry systems, spacecraft computer systems, systems integration and test, and space mission operations. This course is team taught by experts in their respective fields.

**Prerequisites**: An undergraduate degree in physics or engineering or the equivalent. Although preferable, it is not necessary to have taken 615.444 Fundamentals of Space Systems and Subsystems I or 615.744 Fundamentals of Space Systems and Subsystems I.

**Course Notes**: It is not necessary to have previously taken 615.444 Fundamentals of Space Systems and Subsystems I or 615.744 Fundamentals of Space Systems and Subsystems I. This course may be taken for 700-level credit with the additional requirement of a research paper. See 615.745 Fundamentals of Space Systems and Subsystems II

**Instructor**: Pisacane-Coordinator

### 615.446 Physics of Magnetism 🏛

This is an introductory course on the magnetic properties of materials and magnetic systems. The emphasis of the course is a mastery of the physics of magnetism along with detailed examples and applications. A basic review of magnetic fields and various classical applications is given. Topics include the physics of paramagnetism, diamagnetism, and ferromagnetism. The magnetism of metals is presented along with discussion of Landau levels and the quantum Hall effect. Various applications are presented in detail, including magnetic resonance, spectroscopic techniques, magnetoresistance, and spintronics.

**Prerequisites**: An undergraduate degree in engineering, physics, or a related technical discipline. Prior knowledge of electromagnetic interactions would be helpful but not required.

**Instructor**: Faculty

### 615.447 Fundamentals of Sensors 🏛

Students will receive an overview of sensors and methods to build networks and systems using sensors. The physics of detectors, including fundamental technologies and sampling interfaces, will be discussed. Sensor technologies for chemical, biological, nuclear, and radiological detection will be studied in detail. Evaluation methods will be presented for sensor selection based on application-specific information including sensor performance, environmental conditions, and operational impact. DODAF 2.0 methods will be taught, and a project based on several viewpoints will be required and presented. Additional studies will include methods for combining results from various sensors to increase detection confidence. As part of the course, students will be given a threat scenario and will be required to select a sensor suite and networking information to design a hypothetical system considering the threat, sensor deployment cost, and logistics.

**Prerequisite**: An undergraduate degree in engineering, physics, or a related technical discipline.

**Instructor**: Lesho

### 615.448 Alternate Energy Technology

Energy availability and its cost are major concerns to every person. Fossil fuels in general and oil in particular are limited and the world's reserves are depleting. The question asked by many is, "Are there alternatives to the fossil fuel spiral (dwindling supplies and rising costs)?" This course addresses these alternative energy sources. It focuses on the technology basis of these alternate energy methods, as well as the practicality and the potential for widespread use and economic effectiveness. Energy technologies to be considered include photovoltaics, solar thermal, wind energy, geothermal and thermal gradient sources, biomass and synthetic fuels, hydroelectric, wave and tidal energy, and nuclear. The associated methods of energy storage will also be discussed.

**Prerequisite**: An undergraduate degree in engineering, physics, or a related technical discipline.

**Instructor**: Charles

### 615.451 Statistical Mechanics and Thermodynamics

After a brief historical review of thermodynamics and statistical mechanics, the basic principles of statistical mechanics are presented. The classical and quantum mechanical partition functions are discussed and are subsequently used to carry out derivations of the basic thermodynamic properties of several different systems. Topics discussed include Planck's black body radiation derivation and the Einstein–Debye theories of the specific heats of solids. The importance of these topics in the development and confirmation of quantum mechanics is also examined. Other topics discussed include Fermi Dirac and the Bose–Einstein statistics and the cosmic background radiation. The importance of comparisons between theory and data is stressed throughout.

**Instructor**: Kundu

### 615.453 Classical Mechanics

This is an advanced course in classical mechanics that introduces techniques that are applicable to contemporary pure and applied research. The material covered provides a basis for a fundamental understanding of not only quantum and statistical mechanics but also nonlinear mechanical systems. Topics include the Lagrangian and Hamiltonian formulation of classical mechanics, Euler's rigid body equations of motion, Hamilton–Jacobi theory, and canonical perturbation theory. These methods are applied to force-free motion of a rigid body, oscillations of systems of coupled particles, and central force motion including the Kepler problem and scattering in a Coulomb potential. Applications are emphasized through in-class examples and homework.

**Prerequisites**: Intermediate mechanics and 615.441 Mathematical Methods for Physics and Engineering.

**Instructor**: Freund

### 615.454 Quantum Mechanics

This is a course in advanced modern physics that presents the basic concepts and mathematical formalism of quantum mechanics and introduces applications in atomic, molecular, and solid-state physics. Topics include the mathematics of quantum mechanics, one-dimensional problems, central field problems, the interaction of electromagnetic radiation with atomic systems, the harmonic oscillator, angular momentum, and perturbation theory.

**Prerequisite**: 615.441 Mathematical Methods for Physics and Engineering or the equivalent.

**Instructor**: Najmi

### 615.462 Introduction to Astrophysics

The techniques and fundamental theories of modern astrophysics are covered, with special emphasis on the sun and stars. Topics include stellar structure, opacity of gases, radiative and convective transfer of energy, spectroscopic technique, and interpretation of stellar spectra. Stellar and solar magnetism and the role of magnetic fields in stellar atmospheres are also discussed.

**Prerequisites**: 615.442 Electromagnetics or the equivalent and 615.454 Quantum Mechanics.

**Instructor**: Najmi

### 615.465 Modern Physics

This course covers a broad spectrum of topics related to the development of quantum and relativity theories. The understanding of modern physics and its applications is essential to the pursuit of advanced work in materials, optics, and other applied sciences. Topics include the special theory of relativity, particle-like properties of light, wavelike properties of particles, wave mechanics, atomic and nuclear phenomena, elementary particles, statistical physics, solid state, astrophysics, and general relativity.

**Prerequisite**: Undergraduate degree in physics or engineering.

**Instructor**: Hawkins

### 615.471 Principles of Optics 🏛

This course teaches the student the fundamental principles of geometrical optics, radiometry, vision, and imaging and spectroscopic instruments. It begins with a review of basic Gaussian optics to prepare the student for advanced concepts. From Gaussian optics, the course leads the students through the principles of paraxial raytrace analysis to develop a detailed understanding of the properties of an optical system. The causes and techniques for the correction of aberrations are studied. The course covers the design principles of optical instruments, telescopes, microscopes, etc. The techniques of light measurement are covered in sessions on radiometry and photometry.

**Prerequisite**: Undergraduate degree in physics or engineering.

**Instructors**: Edwards, Ohl

### 615.480 Materials Science 🏛

This course covers a broad spectrum of materials-related topics designed to prepare the student for advanced study in the materials arena. Topics include atomic structure, atom and ionic behavior, defects, crystal mechanics, strength of materials, material properties, fracture mechanics and fatigue, phase diagrams and phase transformations, alloys, ceramics, polymers, and composites.

**Prerequisite**: An undergraduate degree in engineering, physics, or a related technical discipline.

**Instructor**: Charles

### 615.481 Polymeric Materials 🏛

This is a comprehensive course in polymeric materials. Topics include natural (biological) polymers, polymer synthesis, polymer morphology, inorganic polymers, ionomers, and polymeric materials applications. Composite materials containing polymers will also be discussed. A portion of the course will be devoted to the evaluation of polymer properties by physical methods.

**Prerequisite**: An undergraduate degree in engineering, physics, or a related technical discipline.

**Instructor**: Faculty

### 615.731 Photovoltaic and Solar Thermal Energy Conversion 🏛

This is an advanced course in the application of science and technology to the field of solar energy in general and photovoltaic and solar thermal energy systems in particular. The foundations of solar energy are described in detail to provide the student with the knowledge to evaluate and/or design complete solar thermal or photovoltaic energy systems. Topics range from the theoretical physical basics of solar radiation to the advanced design of both photovoltaic and solar thermal energy collectors. A major feature of the course is the understanding and design of semiconducting photovoltaic devices (solar cells). Solar cell topics include semiconductors, analysis of p-n junction, Shockley–Queisser limit, nonradiative recombination processes, antireflection coating, crystalline silicon solar cells, thin-film solar cells, and rechargeable batteries. Solar thermal energy topics include solar heat collectors, solar water heaters, solar power systems, sensible heat energy storage, phase transition thermal storage, etc. The course will also present optimizing building designs for a solar energy system.

**Prerequisite**: An undergraduate degree in engineering, physics, or a related technical discipline.

**Instructor**: Sova

### 615.744 Fundamentals of Space Systems and Subsystems I 🔀

This course is intended for the physicist or engineer interested in the design of space experiments and space systems. This class presents the fundamental technical background, current state of the art, and example applications in the development of space systems. Topics include systems engineering, space environment, astrodynamics, propulsion and launch vehicles, attitude determination and control, and space power systems. This course is team taught by experts in their respective fields and requires a research paper.

**Prerequisite**: An undergraduate degree in physics or engineering or the equivalent.

**Course Note**: This course may be taken for 400-level credit without the requirement of a research paper. See 615.444 Fundamentals of Space Systems and Subsystems I.

**Instructor**: Pisacane-Coordinator

### 615.745 Fundamentals of Space Systems and Subsystems II 🏛

This course examines the fundamentals necessary to design and develop space experiments and space systems. The course presents the theoretical background, current state of the art, and examples of the disciplines essential to developing space instrumentation and systems. Experts in the field will cover the following topics: spacecraft attitude determination and control, space communications, satellite command and telemetry systems, satellite data processing and storage, and space systems integration and testing. This course requires the completion of a research paper.

**Prerequisites**: An undergraduate degree in physics or engineering or the equivalent. Although preferable, it is not necessary to have taken 615.444 Fundamentals of Space

Systems and Subsystems I or 615.744 Fundamentals of Space Systems and Subsystems I.

**Course Note**: This course is also offered for 400-level credit and does not require completion of a research paper. See 615.445 Fundamentals of Space Systems and Subsystems II.

**Instructor**: Pisacane-Coordinator

### 615.746 Nanoelectronics: Physics and Devices

This course provides an introduction to state-of-the-art and potential future electronics technologies. The first part of the course focuses on the physics of advanced silicon technology and on its scaling limits. The treatment includes a discussion of future electronics as projected to the year 2012 by the Semiconductor Industry Association's National Technology Roadmap for Semiconductors. This understanding of conventional technology then motivates the second part of the course, which covers some of the "new" physics currently being explored for going beyond the roadmap. Topics range from the reasonably practical to the highly speculative and include tunneling transistors, single-flux quantum logic, single-electronics, spin-based electronics, quantum computing, and perhaps even DNA-based computing. An overview is also given of the prospects for advances in fabrication technology that will largely determine the economic viability for any of these possible electronic futures.

**Prerequisite**: An undergraduate degree in engineering, physics, or a related technical discipline. Familiarity with semiconductor device physics would be helpful.

**Instructor**: Charles

### 615.747 Sensors and Sensor Systems

The primary objective of this course is to present recent advances made in the field of sensors. A broad overview includes optical, infrared, hyperspectral, terahertz, biological, magnetic, chemical, acoustic, and radiation sensors. The course will examine basic sensor operation and the implementation of sensors in measurement systems. Other topics to be covered are physical principles of sensing, interface electronic circuits, and sensor characteristics.

**Instructor**: Fitch

### 615.748 Introduction to Relativity

After a brief review of the theory of special relativity, the mathematical tools of tensor calculus that are necessary for understanding the theory of general relativity will be developed. Relativistic perfect fluids and their stress-energy-momentum tensor will be defined, and the Einstein's field equations will be studied. Gravitational collapse will be introduced, and the Schwarzchild Black Hole solution will be discussed.

**Instructor**: Najmi

### 615.751 Modern Optics

This course covers the fundamental principles of modern physical optics and contemporary optical systems. Topics include propagation of light, polarization, coherence, interference, diffraction, Fourier optics, absorption, scattering, dispersion, and image quality analysis. Special emphasis is placed on the instrumentation and experimental techniques used in optical studies.

**Prerequisite**: 615.442 Electromagnetics or the equivalent completed or taken concurrently.

**Instructor**: Boone

### 615.753 Plasma Physics

This course serves as an introduction to plasma phenomena relevant to energy generation by controlled thermonuclear fusion and space physics. Topics include motion of charged particles in electric and magnetic fields, dynamics of fully ionized plasma from both microscopic and macroscopic points of view, magnetohydrodynamics, equilibria, waves, instabilities, applications to fusion devices, ionospheric, and space physics.

**Prerequisite**: 615.442 Electromagnetics or the equivalent.

**Instructor**: Ukhorskiy

### 615.755 Space Physics

This course studies the solar-terrestrial space environment and its importance for utilization of space. Topics include the solar cycle and magnetic dynamo; the electrodynamics of the solar upper atmosphere responsible for the solar wind; and the solar wind interaction with unmagnetized and magnetized bodies that leads to the treatment of ionospheres, planetary bow shocks, comets, and magnetospheres. Practical issues include penetrating radiation and its effects on spacecraft and man in space, catastrophic discharge phenomena, dust and hypervelocity impacts, material degradation by sputtering and reactive ionospheric constituents, atmospheric heating and orbital drag effects on satellites, and magnetospheric storm disruptions of ground power distribution.

**Prerequisite**: 615.442 Electromagnetics or the equivalent.

**Instructor**: Rymer

### 615.757 Solid-State Physics

Students examine concepts and methods employed in condensed matter physics, with applications in materials science, surface physics, and electronic devices. Topics include atomic and electronic structure of crystalline solids and their role in determining the elastic, transport, and magnetic properties of metals, semiconductors, and insulators. The effects of structural and chemical disorder on these properties are also discussed.

**Prerequisite**: 615.454 Quantum Mechanics or the equivalent.

**Instructor**: Brinkley

**615.758 Modern Topics in Applied Optics** 🏛

This course deals with optical system design involving state-of-the-art concepts. In particular, we will analyze the impact of nonlinearity in the propagation of laser beams and also the stochastic nature of light propagation in some commonly encountered situations such as atmospheric and undersea light propagation. Nonlinear interactions of light and matter play a significant role in a large portion of modern optical systems. In most situations, the optical system designer needs to eliminate or reduce nonlinearities and operate in a so-called linear regime. In other situations, the optical system takes advantage of the nonlinear interaction to produce significantly new operating conditions that are a significant key to the performance of modern optical systems. Similarly, taking into account the stochastic nature of light emission, detection, and propagation is important in the design and analyses of modern optical systems. The course reviews random processes involved in optical systems and applies statistical tools to identify the impact of such processes to the optical system performance.

**Prerequisites**: 615.442 Electromagnetics and 615.782 Optics and MATLAB. A knowledge of laser fundamentals is helpful.

**Instructor**: Torruellas

**615.760 Physics of Semiconductor Devices** 🏛

This course examines the physical principles underlying semiconductor device operation and the application of these principles to specific devices. Emphasis is placed on understanding device operation, rather than on circuit properties. Topics include elementary excitations in semiconductors such as phonons, photons, conduction electrons, and holes; charge and heat transport; carrier trapping and recombination; effects of high doping; contacts; the pn junction; the junction transistor; surface effects; the MIS diode; and the MOSFET. Nanotechnology as applied to electronics will be discussed.

**Prerequisites**: An undergraduate degree in engineering, physics, or a related technical discipline. Some familiarity with quantum mechanics would be helpful.

**Instructor**: Charles

**615.761 Introduction to Oceanography** 🏛

This course covers the physical concepts and mathematics of the exciting field of oceanography and can be taken as an elective. It is designed for the student who wants to learn more about oceanography. Topics range from fundamental small waves to planetary-scale ocean currents. There will be a strong emphasis on understanding the basic ocean processes. Initial development gives a description of how the ocean system works and the basic governing equations. Additional subjects include boundary layers, flow around objects (seamounts), waves, tides, Ekman flow, and the Gulf Stream. Also studied will be the ocean processes that impact our climate such as El Niño and the Thermohaline Conveyor Belt.

**Prerequisite**: Mathematics through calculus.

**Instructor**: Porter

**615.762 Applied Computational Electromagnetics** 🏛

This course introduces the numerical methods and computer tools required for the practical applications of the electromagnetic concepts covered in 615.442 to the daily-life engineering problems. It covers the methods of calculating electromagnetic scattering from complex air and sea targets (aircraft, missiles, ships, etc.), taking into account the effects of the intervening atmosphere and natural surfaces such as the sea surface and terrain. These methods have direct applications in the areas of radar imaging, communications, and remote sensing. Methods for modeling and calculating long-distance propagation over terrain and in urban areas, which find application in the areas of radar imaging, radio and TV broadcasting, and cellular communications, are also discussed. The numerical toolkit built in this course includes the method of moments, the finite difference frequency and time domain methods, the finite element method, marching numerical methods, iterative methods, and the shooting and bouncing ray method.

**Prerequisites**: Knowledge of vector analysis, partial differential equations, Fourier analysis, basic electromagnetics, and a scientific computer language.

**Instructor**: Awadallah

**615.765 Chaos and Its Applications** 🏛

The course will introduce the students to the basic concepts of nonlinear physics, dynamical system theory, and chaos. These concepts will be studied by examining the behavior of fundamental model systems that are modeled by ordinary differential equations and, sometimes, discrete maps. Examples will be drawn from physics, chemistry, and engineering. Some mathematical theory is necessary to develop the material. Practice through concrete examples will help to develop the geometric intuition necessary for work on nonlinear systems. Students conduct numerical experiments using provided software, which allows for interactive learning.

**Prerequisites**: Mathematics through ordinary differential equations. Familiarity with MATLAB is helpful. Consult instructor for more information.

**Course Note**: Access to Whiting School computers is provided for those without appropriate personal computers.

**Instructor**: Liakos

### 615.769 Physics of Remote Sensing

This course exposes the student to the physical principles underlying satellite observations of Earth by optical, infrared, and microwave sensors, as well as techniques for extracting geophysical information from remote sensor observations. Topics will include spacecraft orbit considerations, fundamental concepts of radiometry, electromagnetic wave interactions with land and ocean surfaces and Earth's atmosphere, radiative transfer and atmospheric effects, and overviews of some important satellite sensors and observations. Examples from selected sensors will be used to illustrate the information extraction process and applications of the data for environmental monitoring, oceanography, meteorology, and climate studies.

**Instructor**: Faculty

### 615.772 Cosmology

This course begins with a brief review of tensor calculus and general relativity principles, cosmological models, and theoretical and observational parameters that determine the fate of the universe. Basics of quantum fields necessary for an understanding of the standard model and the early universe will be presented. Hubble expansion, the Cosmic Microwave Background Radiation (CMBR), recent theories of the presence of anisotropy in the CMBR, and their implications will be studied. The horizon problem and the role of the inflationary scenario in the early universe will be thoroughly explored.

**Prerequisite**: 615.748 Introduction to Relativity.

**Instructor**: Najmi

### 615.775 Physics of Climate

To understand the forces that cause global climate variability, we must understand the natural forces that drive our weather and our oceans. This course covers the fundamental science underlying the nature of the Earth's atmosphere and its ocean. This includes development of the basic equations for the atmosphere and ocean, the global radiation balance, description of oceanic and atmospheric processes, and their interactions and variability. Also included will be a description of observational systems used for climate studies and monitoring, and fundamentals underlying global circulation, and climate prediction models.

**Prerequisite**: Undergraduate degree in physics or engineering or equivalent, with strong background in mathematics through the calculus level.

**Instructors**: Porter, Winstead

### 615.778 Computer Optical Design

In this course, students learn to design and analyze optical systems. Students will use a full-function optical ray-trace program (either CODE V, OSLO, or ZEMAX), to be installed on their personal computers or those in the computer lab, to complete their assignments and design project. We will begin with simple lenses for familiarization with the software and then move onto more complicated multi-element lenses and reflective systems. Emphasis is placed on understanding the optical concepts involved in the designs while developing the ability to use the software. Upon completion of the course, students are capable of independently pursuing their own optical designs.

**Prerequisite**: 615.471 Principles of Optics

**Instructor**: Howard

### 615.780 Optical Detectors and Applications

This course examines the physics of detection of incoherent electromagnetic radiation from the infrared to the soft x-ray regions. Brief descriptions of the fundamental mechanisms of device operation are given. Typical source characteristics are mentioned to clarify detection requirements. Descriptions of non-spatially resolving detectors based on photoemission and photo-excitation follow, including background physics, noise, and sensitivity. Practical devices and practical operational constraints are described. Description of scanning formats leads into the description of spatially revolving systems (e.g., staring arrays). Main emphasis is on charge-coupled devices and photo-emissive multiplier tubes such as the image intensifier. Selection of optimum detectors and integration into complete system designs are discussed. Applications in space-based and terrestrial remote sensing are discussed.

**Prerequisite**: 615.471 Principles of Optics is desired; undergraduate-level studies in solid-state physics and mathematics—preferably statistics—is necessary.

**Instructor**: Koerner

### 615.781 Quantum Information Processing

This course provides an introduction to the rapidly developing field of quantum information processing. In addition to covering fundamental concepts such as two-state systems, measurements uncertainty, quantum entanglement, and nonlocality, the course will emphasize specific quantum information protocols. Several applications of this technology will be explored, including cryptography, teleportation, dense coding, computing, and error correction. The quantum mechanics of polarized light will be used to provide a physical context to the discussion. Current research on implementations of these ideas will also be discussed.

**Prerequisite**: 615.454 Quantum Mechanics; familiarity with MATLAB, Mathematica, Python, or equivalent is helpful.

**Instructor**: Clader

### 615.782 Optics and MATLAB

This course provides hands-on experience with MATLAB by performing weekly computer exercises revolving around optics. Each module explores a new topic in optics while simultaneously providing experience in MATLAB. The goal is to bridge the gap between theoretical concepts and real-world applications. Topics include an introduction to MATLAB, Fourier theory and E&M propagation, geometrical optics, optical pattern recognition, geometrical optics and ray tracing through simple optical systems, interference and wave optics, holography and computer-generated holography, polarization, speckle phenomenon, and laser theory and related technology. Students are also expected to complete weekly exercises in MATLAB and a semester project that will allow the student to investigate a particular topic of interest not specifically covered in the course.

**Course Notes**: No prior experience with MATLAB is required. While a background in optics is helpful, it is not required.

**Instructor**: Torruellas

### 615.800 Applied Physics Project

This course is an individually tailored, supervised project that offers the student research experience through work on a special problem related to his or her field of interest. The research problem can be addressed experimentally or analytically, and a written report is produced.

**Prerequisites**: It is recommended that all required Applied Physics courses be completed. The Applied Physics project proposal form (ep. jhu.edu/student-forms) must be approved prior to registration.

**Course Note**: Open only to candidates in the Master of Science in Applied Physics program.

**Instructor**: Charles

### 615.802 Directed Studies in Applied Physics

In this course, qualified students are permitted to investigate possible research fields or to pursue problems of interest through reading or non-laboratory study under the direction of faculty members.

**Prerequisite**: The directed studies program proposal form (ep. jhu.edu/student-forms) must be completed and approved prior to registration.

**Course Note**: Open only to candidates in the Master of Science in Applied Physics program.

**Instructor**: Charles

## APPLIED AND COMPUTATIONAL MATHEMATICS

### 625.201 General Applied Mathematics

This course is designed for students whose prior background does not fully satisfy the mathematics requirements for admission and/ or for students who wish to take a refresher course in applied mathematics. The course provides a review of differential and integral calculus in one or more variables. It covers elementary linear algebra and differential equations, including first- and second-order linear differential equations. Basic concepts of matrix theory are discussed (e.g., matrix multiplication, inversion, and eigenvalues/eigenvectors).

**Prerequisite**: Two semesters of calculus.

**Course Note**: Not for graduate credit.

**Instructor**: Davis

### 625.250 Applied Mathematics I

This course covers the fundamental mathematical tools required in applied physics and engineering. The goal is to present students with the mathematical techniques used in engineering and scientific analysis and to demonstrate these techniques by the solution of relevant problems in various disciplines. Areas include vector analysis, linear algebra, matrix theory, and complex variables.

**Prerequisite**: Differential and integral calculus.

**Course Note**: Not for graduate credit.

**Instructor**: D'Archangelo

### 625.251 Applied Mathematics II

This course is a companion to 625.250. Topics include ordinary differential equations, Fourier series and integrals, the Laplace transformation, Bessel functions and Legendre polynomials, and an introduction to partial differential equations.

**Prerequisite**: Differential and integral calculus. Students with no experience in linear algebra may find it helpful to take 625.250 Applied Mathematics I first.

**Course Note**: Not for graduate credit.

**Instructor**: D'Archangelo

### 625.260 Introduction to Signals and Systems

Linear systems that produce output signals of some type are ubiquitous in many areas of science and engineering. This course will consider such systems, with an emphasis on fundamental concepts as well as the ability to perform calculations for applications in areas such as image analysis, signal processing, computer-aided systems, and feedback control. In particular, the course will approach the topic from the perspectives of both mathematical principles and computational learning. The course will also include examples that span different real-world applications in broad areas such as engineering and medicine. The course is designed primarily for students who do not have a bachelor's degree in electrical engineering or a great deal of prior mathematical coursework. The course will be of value to those with general interests in linear systems analysis, control systems, and/or signal processing. Topics include signal representations, linearity, time-variance, convolution, and Fourier series and transforms. Coverage includes both continuous and discrete-time systems.

**Prerequisite**: Differential and integral calculus.

**Course Note**: Not for graduate credit.

**Instructor**: Woolf

### 625.401 Real Analysis

This course presents a rigorous treatment of fundamental concepts in analysis. Emphasis is placed on careful reasoning and proofs. Topics covered include the completeness and order properties of real numbers, limits and continuity, conditions for integrability and differentiability, infinite sequences, and series. Basic notions of topology and measure are also introduced.

**Prerequisite**: Multivariate calculus.

**Instructor**: Hill

### 625.402 Modern Algebra

This course examines the structures of modern algebra, including groups, linear spaces, rings, polynomials, and fields, and some of their applications to such areas as cryptography, primality testing and the factorization of composite numbers, efficient algorithm design in computing, circuit design, and signal processing. It will include an introduction to quantum information processing. Grading is based on weekly problem sets, a midterm, and a final.

**Prerequisite**: Multivariate calculus and linear algebra.

**Instructor**: Stern

### 625.403 Statistical Methods and Data Analysis

This course introduces commonly used statistical methods. The intent of this course is to provide an understanding of statistical techniques and guidance on the appropriate use of methodologies. The course covers the mathematical foundations of common methods as an aid toward understanding both the types of applications that are appropriate and the limits of the methods. MATLAB and statistical software are used so students can apply statistical methodology to practical problems in the workplace. Topics include the basic laws of probability and descriptive statistics, conditional probability, random variables, expectation and variance, discrete and continuous probability models, bivariate distributions and covariance, sampling distributions, hypothesis testing, method of moments and maximum likelihood point (MLE) estimation, confidence intervals, contingency tables, analysis of variance (ANOVA), and linear regression modeling.

**Prerequisite**: Multivariate calculus.

**Instructors**: Bodt, Savkli, Wang

### 625.404 Ordinary Differential Equations

This course provides an introduction to the theory, solution, and application of ordinary differential equations. Topics discussed in the course include methods of solving first-order differential equations, existence and uniqueness theorems, second-order linear equations, power series solutions, higher-order linear equations, systems of equations, nonlinear equations, Sturm–Liouville theory, and applications. The relationship between differential equations and linear algebra is emphasized in this course. An introduction to numerical solutions is also provided. Applications of differential equations in physics, engineering, biology, and economics are presented. This course covers more material in greater depth than the standard undergraduate-level ODE course.

**Prerequisites**: Two or more terms of calculus are required. Course in linear algebra is helpful.

**Instructor**: Farris

### 625.409 Matrix Theory

In this course, topics include the methods of solving linear equations, Gaussian elimination, triangular factors and row exchanges, vector spaces (linear independence, basis, dimension, and linear transformations), orthogonality (inner products, projections, and Gram–Schmidt process), determinants, eigenvalues and eigenvectors (diagonal form of a matrix, similarity transformations, and matrix exponential), singular value decomposition, and the pseudo-inverse. The course also covers applications to statistics (least squares fitting to linear models, covariance matrices) and to vector calculus (gradient operations and Jacobian and Hessian matrices). MATLAB software will be used in some class exercises.

**Instructors**: Rio, Wall

### 625.411 Computational Methods

As the need to increase the understanding of real-world phenomena grows rapidly, computer-based simulations and modeling tools are increasingly being accepted as viable means to study such problems. In this course, students are introduced to some of the key computational techniques used in modeling and simulation of real-world phenomena. The course begins with coverage of fundamental concepts in computational methods including error analysis, matrices and linear systems, convergence, and stability. It proceeds to curve fitting, least squares, and iterative techniques for practical applications, including methods for solving ordinary differential equations and simple optimization problems. Elements of computer visualization and Monte Carlo simulation will be discussed as appropriate. The emphasis here is not so much on programming technique but rather on understanding basic concepts and principles. Employment of higher-level programming and visualization tools, such as MATLAB, reduces burdens on programming and introduces a powerful tool set commonly used by industry and academia. A consistent theme throughout the course is the linkage between the techniques covered and their applications to real-world problems.

**Prerequisites**: Multivariate calculus and ability to program in MATLAB, FORTRAN, C++, Java, or other language. Courses in matrix theory or linear algebra as well as in differential equations would be helpful but are not required.

**Instructor**: Kuttler

### 625.414 Linear Optimization 🏛

Optimization is the act of obtaining the best result while satisfying given constraints. This course focuses mainly on linear programming and the geometry of linear systems. Though "straightforward" in nature, linear programs have a wide variety of real-world applications such as production planning, worker scheduling, and resource allocation. Linear programming is used in a number of fields: manufacturing, transportation, and military operations are just a few. In this course, we will cover solution techniques for linear programs, including the simplex method, the revised simplex method, the dual simplex method, and, time permitting, interior point methods. We will also investigate linear programming geometry and duality, theorems of the alternative, and sensitivity analysis. In parallel with our theoretical development, we will consider how to formulate mathematical programs for a variety of applications including familiar network models such as the assignment, transshipment, transportation, shortest path, and maximum flow problems. We will also present some methods and applications for integer programming problems (e.g., branch and bound and cutting plane methods) and discuss the role of multi-objective linear programming and goal programming in this area.

**Prerequisites**: Multivariate calculus, linear algebra. Some real analysis is helpful but is not required.

**Instructor**: Castello

### 625.415 Nonlinear Optimization 🏛

Although a number of mathematical programming problems can be formulated and solved using techniques from linear and integer problems, there are a wide variety of problems that require the inclusion of nonlinearities if they are to be properly modeled. This course presents theory and algorithms for solving nonlinear optimization problems. Theoretical topics treated include basic convex analysis, first- and second-order optimality conditions, KKT conditions, constraint qualification, and duality theory. We will investigate an array of algorithms for both constrained and unconstrained optimization. These algorithms include the Nelder–Mead (nonlinear simplex method), steepest descent, Newton methods, conjugate direction methods, penalty methods, and barrier methods. In parallel with our theoretical and algorithmic development, we will consider how to formulate mathematical programs for an assortment of applications including facility location, regression analysis, financial evaluation, and policy analysis. If time permits, we will also address algorithms for special classes of nonlinear optimization problems (e.g., separable programs, convex programs, and quadratic programs).

**Prerequisites**: Multivariate calculus, linear algebra. Some real analysis is helpful but is not required; 625.414 Linear Optimization is not required.

**Instructor**: Castello

### 625.417 Applied Combinatorics and Discrete Mathematics 🏛

Combinatorics and discrete mathematics are increasingly important fields of mathematics because of their extensive applications in computer science, statistics, operations research, and engineering. The purpose of this course is to teach students to model, analyze, and solve combinatorial and discrete mathematical problems. Topics include elements of graph theory, graph coloring and covering circuits, the pigeonhole principle, counting methods, generating functions, recurrence relations and their solution, and the inclusion-exclusion formula. Emphasis is on the application of the methods to problem solving.

**Course Note**: This course is the same as 605.423 Applied Combinatorics and Discrete Mathematics.

**Instructor**: Whisnant

### 625.420 Mathematical Methods for Signal Processing 🏛

This course familiarizes the student with modern techniques of digital signal processing and spectral estimation of discrete-time or discrete-space sequences derived by the sampling of continuous-time or continuous-space signals. The class covers the mathematical foundation needed to understand the various signal processing techniques as well as the techniques themselves. Topics include the discrete Fourier transform, the discrete Hilbert transform, the singular-value decomposition, the wavelet transform, classical spectral estimates (periodogram and correlogram), autoregressive and autoregressive-moving average spectral estimates, and Burg maximum entropy method.

**Prerequisites**: Mathematics through calculus, matrix theory, or linear algebra, and introductory probability theory and/or statistics. Students are encouraged to refer any questions to the instructor.

**Instructor**: Boules

### 625.423 Introduction to Operations Research: Probabilistic Models

This course investigates several probability models that are important to operations research applications. Models covered include Markov chains, Markov processes, renewal theory, queueing theory, scheduling theory, reliability theory, Bayesian networks, random graphs, and simulation. The course emphasizes both the theoretical development of these models and the application of the models to areas such as engineering, computer science, and management science.

**Prerequisites**: Multivariate calculus and a course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis)

**Instructor**: Akinpelu

### 625.436 Graph Theory

This course focuses on the mathematical theory of graphs; a few applications and algorithms will be discussed. Topics include trees, connectivity, Eulerian and Hamiltonian graphs, matchings, edge and vertex colorings, independent sets and cliques, planar graphs, and directed graphs. An advanced topic completes the course.

**Prerequisite**: Familiarity with linear algebra and basic counting methods such as binomial coefficients is assumed. Comfort with reading and writing mathematical proofs is required.

**Instructor**: DeVinney

### 625.438 Neural Networks

This course provides an introduction to concepts in neural networks and connectionist models. Topics include parallel distributed processing, learning algorithms, and applications. Specific networks discussed include Hopfield networks, bidirectional associative memories, perceptrons, feedforward networks with back propagation, and competitive learning networks, including self-organizing and Grossberg networks. Software for some networks is provided.

**Prerequisites**: Multivariate calculus and linear algebra

**Course Note**: This course is the same as 605.447 Neural Networks.

**Instructor**: Fleischer

### 625.441 Mathematics of Finance: Investment Science

This course offers a rigorous treatment of the subject of investment as a scientific discipline. Mathematics is employed as the main tool to convey the principles of investment science and their use to make investment calculations for good decision making. Topics covered in the course include the basic theory of interest and its applications to fixed-income securities, cash flow analysis and capital budgeting, mean-variance portfolio theory and the associated capital asset pricing model, utility function theory and risk analysis, derivative securities and basic option theory, and portfolio evaluation.

**Prerequisites**: Multivariate calculus and an introductory course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis). Some familiarity with optimization is desirable but not necessary.

**Instructor**: Pemy

### 625.442 Mathematics of Risk, Options, and Financial Derivatives

The concept of options stems from the inherent human desire and need to reduce risks. This course starts with a rigorous mathematical treatment of options pricing, credit default swaps, and related areas by developing a powerful mathematical tool known as Ito calculus. We introduce and use the well-known field of stochastic differential equations to develop various techniques as needed, as well as discuss the theory of martingales. The mathematics will be applied to the arbitrage pricing of financial derivatives, which is the main topic of the course. We treat the Black–Scholes theory in detail and use it to understand how to price various options and other quantitative financial instruments. We also discuss interest rate theory. We further apply these techniques to investigate stochastic differential games, which can be used to model various financial and economic situations including the stock market. Time permitting, we discuss related topics in mechanism designs, a subfield of game theory that is concerned about designing economic games with desired outcome.

**Course Notes**: This class is distinguished from 625.441 Mathematics of Finance (formerly 625.439) and 625.714 Introductory Stochastic Differential Equations with Applications, as follows: 625.441 Mathematics of Finance: Investment Science gives a broader and more general treatment of financial mathematics, and 625.714 Introductory Stochastic Differential Equations with Applications provides a deeper (more advanced) mathematical understanding of stochastic differential equations, with applications in both finance and non-finance areas. No one of the classes 625.441 Mathematics of Finance: Investment Science, 625.442 Mathematics of Risk, Options, and Financial Derivatives, and 625.714 Introductory Stochastic Differential Equations with Applications is a prerequisite or co-requisite for the other classes; the classes are intended to be complementary. Feel free to contact the instructor(s) should you have any questions about these courses.

**Prerequisites**: Multivariate calculus, linear algebra and matrix theory (e.g., 625.409 Matrix Theory), and a graduate-level course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis).

**Instructor**: Pemy

### 625.461 Statistical Models and Regression

Introduction to regression and linear models including least squares estimation, maximum likelihood estimation, the Gauss-Markov theorem, and the fundamental theorem of least squares. Topics include estimation, hypothesis testing, simultaneous inference, model diagnostics, transformations, multicollinearity, influence, model building, and variable selection. Advanced topics include nonlinear regression, robust regression, and generalized linear models including logistic and Poisson regression.

**Prerequisites**: One semester of statistics (such as 625.403 Statistical Methods of Data Analysis), multivariate calculus, and linear algebra.

**Instructor**: Hung

### 625.462 Design and Analysis of Experiments

Statistically designed experiments are the efficient allocation of resources to maximize the amount of information obtained with a minimum expenditure of time and effort. Design of experiments is applicable to both physical experimentation and computer simulation models. This course covers the principles of experimental design, the analysis of variance method, the differences between fixed and random effects and between nested and crossed effects, and the concept of confounded effects. The designs covered include completely random, randomized block, Latin squares, split-plot, factorial, fractional factorial, nested treatments and variance component analysis, response surface, optimal, Latin hypercube, and Taguchi. Any experiment can correctly be analyzed by learning how to construct the applicable design structure diagram (Hasse diagrams).

**Prerequisites**: Multivariate calculus, linear algebra, and one semester of graduate probability and statistics (e.g., 625.403 Statistical Methods and Data Analysis). Some computer-based homework assignments will be given.

**Instructor**: Bodt

### 625.463 Multivariate Statistics and Stochastic Analysis

Multivariate analysis arises with observations of more than one variable when there is some probabilistic linkage between the variables. In practice, most data collected by researchers in virtually all disciplines are multivariate in nature. In some cases, it might make sense to isolate each variable and study it separately. In most cases, however, the variables are interrelated in such a way that analyzing the variables in isolation may result in failure to uncover critical patterns in the data. Multivariate data analysis consists of methods that can be used to study several variables at the same time so that the full structure of the data can be observed and key properties can be identified. This course covers estimation, hypothesis tests, and distributions for multivariate mean vectors and covariance matrices. We also cover popular multivariate data analysis methods including multivariate data visualization, maximum likelihood, principal components analysis, multiple comparisons tests, multi-dimensional scaling, cluster analysis, discriminant analysis and multivariate analysis of variance, multiple regression and canonical correlation, and analysis of repeated measures data. Course work will include computer assignments.

**Prerequisites**: Linear algebra, multivariate calculus, and one semester of graduate probability and statistics (e.g., 625.403 Statistical Methods of Data Analysis).

**Instructor**: Hung

### 625.464 Computational Statistics

Computational statistics is a branch of mathematical sciences concerned with efficient methods for obtaining numerical solutions to statistically formulated problems. This course will introduce students to a variety of computationally intensive statistical techniques and the role of computation as a tool of discovery. Topics include numerical optimization in statistical inference [expectation-maximization (EM) algorithm, Fisher scoring, etc.], random number generation, Monte Carlo methods, randomization methods, jackknife methods, bootstrap methods, tools for identification of structure in data, estimation of functions (orthogonal polynomials, splines, etc.), and graphical methods. Additional topics may vary. Course work will include computer assignments.

**Prerequisites**: Multivariate calculus, familiarity with basic matrix algebra, graduate course in probability and statistics (such as 625.403 Statistical Methods of Data Analysis)

**Instructor**: Nickel

**625.468 Statistical Privacy Protection in Large Datasets**

This course presents statistical methods for limiting the information available to users of data products derived from large datasets. Such limitation often involves anonymizing the records in a dataset; i.e., making it impossible to determine the identity of the entity (person, household, company) associated with each record. It may also involve limiting the precision of the information released for a known entity. Within survey statistics, this topic is called 'statistical disclosure control (or limitation)'. Within data mining, such methods are called 'privacy-preserving'. We begin by discussing various definitions of privacy and confidentiality related to data that entities contribute (perhaps unknowingly) to large dataset(s) maintained by an organization. We define types of disclosure (e.g., identity, attribute) and give examples of each. Most of the course will involve analysis of various methods that have been developed by statisticians and computer scientists working at governmental statistical agencies, at high tech firms, and in academia. The analysis of a method begins by simulating a realistic dataset from some field (demographics, economics, social media, genetics), deciding what data products (e.g., a set of records, a set of tables, or a model) are likely to be produced from this data, and what types of disclosures are of greatest concern. Then we apply the method to the data (e.g., adding noise, smoothing, suppressing selected data values) and determine if the method has sufficiently lowered the risk of disclosure without greatly lessening data quality. These methods can sometimes be illustrated with textbook-type examples. Some examples will require use of Excel, MATLAB, or similar computing tool. Basic knowledge of statistical distributions is required. Knowledge of linear programming is useful for some topics but is not required.

**Prerequisite**: 625.403 Statistical Methods and Data Analysis (or similar course).

**Instructor**: Massell

**625.480 Cryptography**

An important concern in the information age is the security, protection, and integrity of electronic information, including communications, electronic funds transfer, power system control, transportation systems, and military and law enforcement information. Modern cryptography, in applied mathematics, is concerned not only with the design and exploration of encryption schemes (classical cryptography) but also with the rigorous analysis of any system that is designed to withstand malicious attempts to tamper with, disturb, or destroy it. This course introduces and surveys the field of modern cryptography. After mathematical preliminaries from probability theory, algebra, computational complexity, and number theory, we will explore the following topics in the field: foundations of cryptography, public key cryptography, probabilistic proof systems, pseudorandom generators, elliptic curve cryptography, and fundamental limits to information operations.

**Prerequisites**: Linear algebra and an introductory course in probability and statistics such as 625.403 Statistical Methods and Data Analysis.

**Instructor**: Nickel

**625.485 Number Theory**

This course covers principal ideas of classical number theory, including the fundamental theorem of arithmetic and its consequences, congruences, cryptography and the RSA method, polynomial congruences, primitive roots, residues, multiplicative functions, and special topics.

**Prerequisites**: Multivariate calculus and linear algebra.

**Instructor**: Stern

**625.487 Applied Topology**

The course is both an introduction to topology and an investigation of various applications of topology in science and engineering. Topology, simply put, is a mathematical study of shapes, and it often turns out that just knowing a rough shape of an object (whether that object is as concrete as platonic solids or as abstract as the space of all paths in large complex networks) can enhance one's understanding of the object. We will start with a few key theoretical concepts from point-set topology with proofs, while letting breadth take precedence over depth, and then introduce key concepts from algebraic topology, which attempts to use algebraic concepts, mostly group theory, to develop ideas of homotopy, homology, and cohomology, which render topology "computable." Finally, we discuss a few key examples of real-world applications of computational topology, an emerging field devoted to the study of efficient algorithms for topological problems, especially those arising in science and engineering, which builds on classical results from algebraic topology as well as algorithmic tools from computational geometry and other areas of computer science. The questions we like to ask are: Do I know the topology of my network? What is a rough shape of the large data set that I am working with (is there a logical gap?) Will the local picture of a part of the sensor field I am looking at give rise to a consistent global common picture?

**Prerequisites**: Multivariate calculus, linear algebra and matrix theory (e.g., 625.409 Matrix Theory), and an undergraduate-level course in probability and statistics.

**Course Note**: This course is the same as 605.428 Applied Topology.

**Instructor**: Boswell, Sorokina

### 625.490 Computational Complexity and Approximation 🏛

This course will cover the theory of computational complexity, with a focus on popular approximation and optimization problems and algorithms. It begins with important complexity concepts including Turing machines, Karp and Turing reducibility, basic complexity classes, and the theory of NP-completeness. It then discusses the complexity of well-known approximation and optimization algorithms and introduces approximability properties, with special focus on approximation algorithm and heuristic design. The impact of emerging computing techniques, such as massive parallelism and quantum computing, will also be discussed. The course will specifically target algorithms with practical significance and techniques that can improve performance in real-world implementations.

**Prerequisites**: Introductory probability theory and/or statistics (such as 625.403 Statistical Methods of Data Analysis) and undergraduate-level exposure to algorithms and matrix algebra. Some familiarity with optimization and computing architectures is desirable but not necessary.

**Instructor**: Davis

### 625.492 Probabilistic Graphical Models 🔀

This course introduces the fundamentals behind the mathematical and logical framework of graphical models. These models are used in many areas of machine learning and arise in numerous challenging and intriguing problems in data analysis, mathematics, and computer science. For example, the "big data" world frequently uses graphical models to solve problems. While the framework introduced in this course will be largely mathematical, we will also present algorithms and connections to problem domains. The course will begin with the fundamentals of probability theory and will then move into Bayesian networks, undirected graphical models, template-based models, and Gaussian networks. The nature of inference and learning on the graphical structures will be covered, with explorations of complexity, conditioning, clique trees, and optimization. The course will use weekly problem sets and a term project to encourage mastery of the fundamentals of this emerging area.

**Prerequisites**: Graduate course in probability and statistics (such as 625.403 Statistical Methods of Data Analysis).

**Course Note**: This course is the same as 605.425 Probabilistic Graphical Models.

**Instructor**: Woolf

### 625.495 Time Series Analysis and Dynamic Modeling 🏛

This course will be a rigorous and extensive introduction to modern methods of time series analysis and dynamic modeling. Topics to be covered include elementary time series models, trend and seasonality, stationary processes, Hilbert space techniques, the spectral distribution function, autoregressive/integrated/moving average (ARIMA) processes, fitting ARIMA models, forecasting, spectral analysis, the periodogram, spectral estimation techniques, multivariate time series, linear systems and optimal control, state-space models, and Kalman filtering and prediction. Additional topics may be covered if time permits. Some applications will be provided to illustrate the usefulness of the techniques.

**Prerequisites**: Graduate course in probability and statistics (such as 625.403 Statistical Methods of Data Analysis) and familiarity with matrix theory and linear algebra.

**Course Note**: This course is also offered in the full-time Department of Applied Mathematics & Statistics (Homewood campus).

**Instructor**: Pemy

### 625.703 Functions of a Complex Variable 🏛

Topics include properties of complex numbers, analytic functions, Cauchy's theorem and integral formulas, Taylor and Laurent series, singularities, contour integration and residues, and conformal mapping.

**Prerequisites**: 625.401 Real Analysis, or 625.404 Ordinary Differential Equations, or permission of the instructor.

**Instructors**: Weisman, Whisnant

### 625.710 Fourier Analysis with Applications to Signal Processing and Differential Equations 🏛

This applied course covers the theory and application of Fourier analysis, including the Fourier transform, the Fourier series, and the discrete Fourier transform. Motivation will be provided by the theory of partial differential equations arising in physics and engineering. We will also cover Fourier analysis in the more general setting of orthogonal function theory. Applications in signal processing will be discussed, including the sampling theorem and aliasing, convolution theorems, and spectral analysis. Finally, we will discuss the Laplace transform, again with applications to differential equations.

**Prerequisites**: Familiarity with differential equations, linear algebra, and real analysis.

**Instructor**: Kuttler

**625.714 Introductory Stochastic Differential Equations with Applications**

The goal of this course is to give basic knowledge of stochastic differential equations useful for scientific and engineering modeling, guided by some problems in applications. The course treats basic theory of stochastic differential equations, including weak and strong approximation, efficient numerical methods and error estimates, the relation between stochastic differential equations and partial differential equations, Monte Carlo simulations with applications in financial mathematics, population growth models, parameter estimation, and filtering and optimal control problems.

**Prerequisites**: Multivariate calculus and a graduate course in probability and statistics, as well as exposure to ordinary differential equations.

**Instructor**: Pemy

**625.717 Advanced Differential Equations: Partial Differential Equations**

This course presents practical methods for solving partial differential equations (PDEs). The course covers solutions of hyperbolic, parabolic, and elliptic equations in two or more independent variables. Topics include Fourier series, separation of variables, existence and uniqueness theory for general higher-order equations, eigenfunction expansions, finite difference and finite element numerical methods, Green's functions, and transform methods. MATLAB, a high-level computing language, is used throughout the course to complement the analytical approach and to introduce numerical methods.

**Prerequisites**: 625.404 Ordinary Differential Equations or equivalent graduate-level ordinary differential equations class and knowledge of eigenvalues and eigenvectors from matrix theory. (Note: The standard undergraduate-level ordinary differential equations class alone is not sufficient to meet the prerequisites for this class.)

**Instructors**: Farris, Whisnant

**625.718 Advanced Differential Equations: Nonlinear Differential Equations and Dynamical Systems**

This course examines ordinary differential equations from a geometric point of view and involves significant use of phase-plane diagrams and associated concepts, including equilibrium points, orbits, limit cycles, and domains of attraction. Various methods are discussed to determine existence and stability of equilibrium points and closed orbits. Methods are discussed for analyzing nonlinear differential equations (e.g., linearization, direct, perturbation, and bifurcation analysis). An introduction to chaos theory and Hamiltonian systems is also presented. The techniques learned will be applied to equations from physics, engineering, biology, ecology, and neural networks (as time permits).

**Prerequisites**: 625.404 Ordinary Differential Equations or equivalent graduate-level ordinary differential equations class and knowledge of eigenvalues and eigenvectors from matrix theory. (Note: The standard undergraduate-level ordinary differential equations class alone is not sufficient to meet the prerequisites for this class.) 625.717 Advanced Differential Equations: Partial Differential Equations is not required.

**Instructors**: Farris, Whisnant

**625.721 Probability and Stochastic Process I**

This rigorous course in probability covers probability space, random variables, functions of random variables, independence and conditional probabilities, moments, joint distributions, multivariate random variables, conditional expectation and variance, distributions with random parameters, posterior distributions, probability generating function, moment generating function, characteristic function, random sum, types of convergence and relation between convergence concepts, law of large numbers and central limit theorem (i.i.d. and non-i.i.d. cases), Borel-Cantelli Lemmas, well known discrete and continuous distributions, homogenous Poisson process (HPP), non-homogenous Poisson process (NHPP), and compound Poisson process. This course is proof oriented. The primary purpose of this course is to lay the foundation for the second course, 625.722 Probability and Stochastic Process II, and other specialized courses in probability. Note that, in contrast to 625.728 Theory of Probability, this course is largely a non-measure theoretic approach to probability.

**Prerequisites**: Multivariate calculus and 625.403 Statistical Methods and Data Analysis or equivalent.

**Instructor**: Aminzadeh

**625.722 Probability and Stochastic Process II**

This course is an introduction to theory and applications of stochastic processes. The course starts with a brief review of conditional probability, conditional expectation, conditional variance, central limit theorems, and Poisson Process. The topics covered include: Gaussian random vectors and processes, renewal processes, renewal reward process, discrete-time Markov chains, classification of states, birth-death process, reversible Markov chains, branching process, continuous-time Markov chains, limiting probabilities, Kolmogorov differential equations, approximation methods for transition probabilities, random walks, and martingales. This course is proof oriented.

**Prerequisites**: Differential equations and 625.721 Probability and Stochastic Process I or equivalent.

**Instructor**: Aminzadeh

### 625.725 Theory of Statistics I

This course covers mathematical statistics and probability. Topics covered include discrete and continuous probability distributions, expected values, moment-generating functions, sampling theory, convergence concepts, and the central limit theorem. This course is a rigorous treatment of statistics that lays the foundation for 625.726 Theory of Statistics II and other advanced courses in statistics.

**Prerequisites**: Multivariate calculus and 625.403 Statistical Methods and Data Analysis or equivalent.

**Instructor**: Aminzadeh

### 625.726 Theory of Statistics II

This course is the continuation of 625.725. It covers method of moments estimation, maximum likelihood estimation, the Cramér–Rao inequality, sufficiency and completeness of statistics, uniformly minimum variance unbiased estimators, the Neyman–Pearson Lemma, the likelihood ratio test, goodness-of-fit tests, confidence intervals, selected non-parametric methods, and decision theory.

**Prerequisite**: 625.725 Theory of Statistics I or equivalent.

**Instructor**: Aminzadeh

### 625.728 Theory of Probability

This course provides a rigorous, measure-theoretic introduction to probability theory. It begins with the notion of fields, sigma-fields, and measurable spaces and also surveys elements from integration theory and introduces random variables as measurable functions. It then examines the axioms of probability theory and fundamental concepts including conditioning, conditional probability and expectation, independence, and modes of convergence. Other topics covered include characteristic functions, basic limit theorems (including the weak and strong laws of large numbers), and the central limit theorem.

**Prerequisites**: 625.401 Real Analysis and 625.403 Statistical Methods and Data Analysis.

**Instructor**: Hill

### 625.734 Queuing Theory with Applications to Computer Science

Queues are a ubiquitous part of everyday life; common examples are supermarket checkout stations, help desk call centers, manufacturing assembly lines, wireless communication networks, and multi-tasking computers. Queuing theory provides a rich and useful set of mathematical models for the analysis and design of service process for which there is contention for shared resources. This course explores both theory and application of fundamental and advanced models in this field. Fundamental models include single and multiple server Markov queues, bulk arrival and bulk service processes, and priority queues. Applications emphasize communication networks and computer operations but may include examples from transportation, manufacturing, and the service industry. Advanced topics may vary.

**Prerequisites**: Multivariate calculus and a graduate course in probability and statistics such as 625.403 Statistical Methods and Data Analysis.

**Course Note**: This course is the same as 605.725 Queuing Theory with Applications to Computer Science.

**Instructor**: Nickel

### 625.740 Data Mining

The field of data science is emerging to make sense of the growing availability and exponential increase in size of typical data sets. Central to this unfolding field is the area of data mining, an interdisciplinary subject incorporating elements of statistics, machine learning, artificial intelligence and data processing. In this course, we will explore methods for preprocessing, visualizing and making sense of data, focusing not only on the methods, but also on the mathematical foundations of many of the algorithms of statistics and machine learning. We will learn about approaches to classification, including traditional methods such as Bayes Decision Theory and more modern approaches such as Support Vector Machines and unsupervised learning techniques that encompass clustering algorithms applicable when labels of the training data are not provided or are unknown. We will introduce and use open-source statistics and data mining software such as R and Weka. Students will have an opportunity to see how data mining algorithms work together by reviewing case studies and exploring a topic of choice in more detail by completing a project over the course of the semester.

**Prerequisites**: Multivariate calculus, linear algebra, and matrix theory (e.g., 625.409 Matrix Theory), and a course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis). This course will also assume familiarity with multiple linear regression and basic ability to program.

**Instructor**: Weisman

### 625.741 Game Theory

Game theory is a field of applied mathematics that describes and analyzes interactive decision making when two or more parties are involved. Since finding a firm mathematical footing in 1928, it has been applied to many fields, including economics, political science, foreign policy, and engineering. This course will serve both as an introduction to and a survey of applications of game theory. Therefore, after covering the mathematical foundational work with some measure of mathematical rigor, we will examine many real-world situations, both historical and current. Topics include two-person/N-person game, cooperative/noncooperative game, static/dynamic game, and combinatorial/strategic/coalitional game, as well as their respective examples and applications. Further attention will be given to the meaning and the computational complexity of finding of Nash equilibrium.

**Prerequisites**: Multivariate calculus, linear algebra and matrix theory (e.g., 625.409 Matrix Theory), and a course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis).

**Course Note**: This course is the same as 605.726 Game Theory.
**Instructor**: Henry

### 625.743 Stochastic Optimization and Control

Stochastic optimization plays an increasing role in the analysis and control of modern systems. This course introduces the fundamental issues in stochastic search and optimization, with special emphasis on cases where classical deterministic search techniques (steepest descent, Newton–Raphson, linear and nonlinear programming, etc.) do not readily apply. These cases include many important practical problems, which will be briefly discussed throughout the course (e.g., neural network training, nonlinear control, experimental design, simulation-based optimization, sensor configuration, image processing, discrete-event systems, etc.). Both global and local optimization problems will be considered. Techniques such as random search, least mean squares (LMS), stochastic approximation, simulated annealing, evolutionary computation (including genetic algorithms), and machine learning will be discussed.

**Prerequisites**: Multivariate calculus, linear algebra, and one semester of graduate probability and statistics (e.g., 625.403 Statistical Methods and Data Analysis). Some computer-based homework assignments will be given. It is recommended that this course be taken only in the last half of a student's degree program.

**Instructor**: Spall

### 625.744 Modeling, Simulation, and Monte Carlo

Computer simulation and related Monte Carlo methods are widely used in engineering, scientific, and other work. Simulation provides a powerful tool for the analysis of real-world systems when the system is not amenable to traditional analytical approaches. In fact, recent advances in hardware, software, and user interfaces have made simulation a "first-line" method of attack for a growing number of problems. Areas in which simulation-based approaches have emerged as indispensable include decision aiding, prototype development, performance prediction, scheduling, and computer-based personnel training. This course introduces concepts and statistical techniques that are critical to constructing and analyzing effective simulations and discusses certain applications for simulation and Monte Carlo methods. Topics include random number generation, simulation-based optimization, model building, bias-variance trade-off, input selection using experimental design, Markov chain Monte Carlo (MCMC), and numerical integration.

**Prerequisites**: Multivariate calculus, familiarity with basic matrix algebra, graduate course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis). Some computer-based homework assignments will be given. It is recommended that this course be taken only in the last half of a student's degree program.

**Instructor**: Hill

### 625.800 Independent Study in Applied and Computational Mathematics

An individually tailored, supervised project on a subject related to applied and computational mathematics. A maximum of one independent study course may be applied toward the master of science degree or post-master's certificate. This course may only be taken in the second half of a student's degree program. All independent studies must be supervised by an ACM instructor and must rely on material from prior ACM courses. The independent study project proposal form must be approved prior to registration.

**Instructor**: Faculty

## INFORMATION SYSTEMS ENGINEERING

### 635.401 Foundations of Information Systems Engineering

Creating and operating large-scale information systems requires a holistic approach that manages the blending of software, hardware, networks, and security inherent in modern systems. This course introduces key elements and processes required for designing, analyzing, developing, and integrating complex information systems. The course focuses on the systems engineering approach, with specific emphasis on design, development, and deployment. Topics covered include requirements engineering, architecture development, security engineering, cost-benefit analysis, information and networking technologies, and operations.

**Instructors**: Chavis, Valenta

### 635.411 Principles of Network Engineering

This course provides an technical, introductory overview of networking and telecommunications for the engineering practitioner. Topics include voice, data, and video communication system fundamentals, including signaling, frequency concepts, transmission media, multiplexing, spread spectrum, signal encoding, error control, and basic terminology. The OSI and TCP/IP reference models are examined along with the basic concepts of protocols, service interfaces, encapsulation, and layering. The course also covers networking and telecommunication techniques, applications technology, and networking topologies and internetworking architectures. Specific areas discussed include LAN system fundamentals, such as Ethernet and IEEE 802.11 wireless; and WAN system fundamentals, such as circuit-switching, packet-switching, IP routing, cellular, satellite, frame relay, label switching, and Asynchronous Transfer Mode.

**Instructors**: Burbank, Romano

### 635.421 Principles of Decision Support Systems

This course focuses on the use and application of information systems to support the decision-making process. Knowledge-based systems, neural networks, expert systems, electronic meeting systems, group systems, and web-based systems are discussed as a basis for designing and developing highly effective decision support systems. Data models, interactive processes, knowledge-based approaches, and integration with database systems are also described. Theoretical concepts are applied to real-world applications.

**Instructor**: Felikson

### 635.461 Principles of Human-Computer Interaction

Well-designed human–computer interaction (HCI) is critical to the success of computer and information systems. This course focuses on the HCI design process and covers the underlying scientific principles, HCI design methodology, and the user-interface technology used to implement HCI. Topics include human cognition, HCI theories, user observation and task analysis, prototyping and evaluation techniques, user interface modalities and graphical user interface components, and accessibility. Selected additional topics may include HCI in website design, support of collaborative work, human interaction with automation, and ubiquitous computing. Student design projects are an integral part of the course. Reading the current HCI research literature is also required.

**Instructor**: Montemayer

### 635.471 Data Recovery and Continuing Operations

Data recovery and continuing operations refers to the processes, plans, and technologies required for an enterprise to achieve resiliency given unexpected events that may disrupt IT operations. This course provides an overview of the storage technologies to address backup, disaster recovery, and business continuity. Technologies that address auditing, redundancy, and resiliency in the infrastructure (e.g., networks, power, cooling, etc.) are described. Beyond the technologies, processes and plans for continuing operations are covered, including issues such as business continuity, disaster recovery, and risk management.

**Prerequisite**: 635.421 Principles of Decision Support Systems is recommended and may be taken concurrently.

**Instructor**: Cost

### 635.472 Privacy Engineering

Personal information has become a new class of digital property with immense value in commerce but also critical to the effectiveness of national security and intelligence. Virtually any information system must be engineered to comply with increasingly complex public laws protecting privacy while also preserving the information's value to business, national security, and law enforcement. This course dismantles the various sources of domestic and international rules, including Federal directives such as DoD-5240-1.R, EO 12333, and USSID SP00018, and empowers students to be more effective in designing and executing systems and applications that will successfully navigate those rules.

**Instructor**: Ritter

### 635.476 Information Systems Security

This course describes the systems security engineering process, with a focus on security during the design and implementation of information systems. Topics include design principles, risk assessment, and security metrics. The course will present the processes that have been defined and published by the federal government for designing and evaluating secure information systems.

**Instructors**: Pak, Resch

### 635.482 Website Development

This course covers the design and implementation of websites. Various web standards, as developed by the World Wide Web Consortium and by browser manufacturers, are studied. HTML 4.01 and XHTML 1.0 specifications are covered, including topics such as text control, images, hypertext links, tables, frames, and embedded objects (e.g., video and applets). Cascading style sheets (CSS1 and CSS2), a web scripting language (such as JavaScript), CGI programming, and their use in Dynamic HTML are also covered. Design and development topics include ease of navigation, download time, maintaining a consistent look and feel across multiple pages, making a website work well across multiple browsers, and web server selection and configuration.

**Instructor**: Noble

### 635.483 E-Business: Models, Architecture, Technologies and Infrastructure

This course explores fundamental aspects of the e-Business (electronic business) phenomenon that is currently sweeping through the global economy, as well as design principles and technology used to build computer-based systems in order to support the notion of e-Business. e-Business is an umbrella term, an interdisciplinary topic encompassing both business and technology. This topic addresses a variety of business activities, business processes, and strategic business functions conducted over the Internet in order to service customers, collaborate with business partners, and maintain and sustain competitive advantage in the networking economy. The course introduces contemporary management philosophies as they have come to be used for the marketing, selling, and distribution of goods and services through the Internet and other electronic media. The course explores approaches of defining drivers and use cases of conducting electronic business. This course provides an overview of principles and analysis of different models of electronic business. It enables students to design effective e-Business models built on a foundation of business concepts, knowledge of the e-Business environment, and an understanding of the influence of the Internet on business stakeholders, including customers, suppliers, manufacturers, service makers, regulators, managers, and employees. In this course students undertake value analysis and learn to describe value propositions. Business architecture and software infrastructure used to engineer and build e-Business systems will be explained. The modern information technologies associated with the delivery of business capabilities over the Internet will be discussed. The course content will be reinforced by a variety of assignments.

**Instructors**: Chittargi, Felikson

### 635.711 Advanced Topics in Network Engineering

This course is designed to provide an advanced treatment of key topic areas in networking and telecommunications for students who have mastered the basic principles of network engineering. Key operational systems, protocols, and technologies are explored in local, wide, metro-area, storage, and wireless networking. Major topic areas include advanced LAN/WLAN technologies (Power over Ethernet, IEEE 802.1x authentication, VLANs, link aggregation, etc.), storage area network technologies, virtualized/ cloud networking, optical networking, IPv6, Spanning Tree and Dynamic IP routing protocols, "last-mile" networking (DSL, cable modems, etc.), label switching, multicasting, multicast routing, real-time application support mechanisms, quality of service protocols, Advanced Transport Layer topics (congestion notification, TCP options, etc.), and network security (address translation, VPNs, stateful inspection, etc.). A major component of the course will be a design project on one of the topic areas covered in the class.

**Prerequisite**: 635.411 Principles of Network Engineering or 605.471 Principles of Data Communications Networks or equivalent.

**Instructor**: Romano

### 635.775 Cyber Policy, Law, and Cyber Crime Investigation

Technical solutions for investigating cyber attacks and restoring our information systems must be balanced against, and work within, laws, regulations, and policies that govern information technology. The objective of this course is to provide a comprehensive overview of the legal and policy structures that must be considered in building effective compliance, investigation, and enforcement capabilities. Students will explore offensive and defensive aspects of evidence collection, forensic investigation, privacy, reporting, and implementing corrective actions. Students will develop and submit a management plan for improving compliance, investigation, and enforcement capabilities within an organization's systems. Upon completing this course, students will be able to provide improved leadership within the teams that manage compliance, investigation, and enforcement; increase their ability to collaborate with legal and business stakeholders; and improve their ability to develop policies that align to legal requirements.

**Instructor**: Ritter

### 635.776 Building Information Governance

Businesses and government agencies confront increasingly complex rules and standards establishing the requirements for how digital information assets are to be created, stored, maintained, accessed, transmitted, received, and disposed. Information system engineers face enormous compliance risks, functional inefficiencies, and remediation costs if they are unprepared to navigate and master all of the technology, business, and legal rules against which digital information must be governed. All of these variables have become more complex as governments and industry partner more closely in counterterrorism investigations and defenses. This course enables engineers to explore and understand these rules and to develop better leadership skills across teams engaged in designing and managing complex governance projects. Assignments will expose engineers to, and teach them to navigate, the traps that global, cloud-based services present. Students completing the course will be able to contribute effectively to the cutting-edge, demanding projects ahead—"big data" transactions, real-time reporting to official agencies, electronic discovery, privacy, and compliance. Students will be expected to actively participate in class exercises, complete written assignments, and develop and present a final written governance proposal.

**Instructor**: Ritter

### 635.795 Information Systems Engineering Capstone Project

This course is designed for students who would like to conduct a major independent project involving a substantial enterprise information system design that builds on elements of the Information Systems Engineering (ISE) curriculum. The project includes requirements analysis, IT architecture design, network design, software integration, decision support applications, and deployment planning. Interim deliverables include presentations to the course advisors. Project proposals are required and a mentor will be assigned to the student.

**Prerequisites**: Completion of eight courses in the ISE curriculum, including all ISE foundation courses.

**Course Note**: Students may not receive graduate credit for both 635.795 and 635.802 Independent Study in Information Systems Engineering II.

**Instructor**: Faculty

### 635.801 Independent Study in Information Systems Engineering I

This course permits graduate students in Information Systems Engineering (ISE) to work with a faculty mentor to explore a topic in depth or conduct research in selected areas. Requirements for completion include submission of a significant paper.

**Prerequisites**: Seven ISE graduate courses including the foundation courses, three track-focused courses, and two courses numbered 635.7xx; or admission to the post-master's certificate. Students must also have permission of a faculty mentor, the student's academic advisor, and the program chair.

### 635.802 Independent Study in Information Systems Engineering II

Students wishing to take a second independent study in Information Systems Engineering (ISE) should sign up for this course.

**Prerequisites**: 635.801 Independent Study in Information Systems Engineering I and permission of a faculty mentor, the student's academic advisor, and the program chair.

**Course Note**: Students may not receive graduate credit for both 635.802 and 635.795 Information Systems Engineering Capstone Project.

## SYSTEMS ENGINEERING

### 645.450 Foundations of Human Systems Engineering

Systems are designed, built, and used by humans. Their purpose is to help people meet their goals and perform their tasks. This course introduces the foundations of human systems engineering (HSE) from which system requirements and design elements are derived. The objective is to provide students with the knowledge of human capabilities and introduce human systems engineering concepts and design principles. Human capabilities include visual, auditory, and touch senses; motion; cognitive processing; and decision making. Human systems engineering concepts and design principles include human factors engineering; training; maintenance; environmental, safety, and health; survivability; habitability; manpower; and personnel.

**Prerequisite**: 645.462 Introduction to Systems Engineering.

**Instructors**: Beecher, McKneely

### 645.451 Integrating Humans and Technology

In this course students will learn how to integrate the human into the system and to derive human-based system requirements and design elements. Design preparation will comprise collecting/compiling missions, scenarios, user profiles, and conceptual designs. Human-system analysis processes will introduce work flow; task; social and communications networks; and gap, function, decision, and risk analyses. Topics include culture and team dynamics; modeling and simulation of human capabilities; human-centered prototyping; human performance measurement; supervision of automation; human considerations in system integration, production, and deployment; and user support.

**Prerequisite**: 645.462 Introduction to Systems Engineering.

**Instructors**: Fitzpatrick, Straub

**645.462 Introduction to Systems Engineering**

This course introduces students to the fundamental principles of systems engineering and their application to the development of complex systems. It describes how the systems engineering viewpoint differs from that of the engineering specialist, as well as the essential role that systems engineering plays as an integral component of program management. Topics include requirements analysis, concept definition, system synthesis, design trade-offs, risk assessment, interface definition, engineering design, system integration, and related systems engineering activities. The course defines the breadth and depth of the knowledge that the systems engineer must acquire concerning the characteristics of the diverse components that constitute the total system. Special topics such as simulation and models and test and evaluation are discussed in relation to the systems engineering viewpoint. Students address typical systems engineering problems that highlight important issues and methods of technical problem resolution.

**Prerequisites**: An engineering, science, or mathematics degree and one year of experience in science or engineering, or permission from the student's academic advisor and the course instructor

**Instructors**: Biemer, Brown, Dever, Devereux, Hein, Holub, Kane, Pardoe, Saleh, Sweeney, Syed, Thompson, Wells

**645.467 Management of Systems Projects**

The course addresses the management of a technical project from concept to operational use, with emphasis on the functions, roles, and responsibilities of the project manager. From the development of a proposal to the delivery of a product to a customer, the efforts to conceive, plan, budget, schedule, monitor, control/direct, and report the progress of the project are discussed. Throughout the project life cycle, the need for good communications, interface and configuration management, and conflict resolution is emphasized. Students assume the role of project managers who must use management tools such as WBS, EVM, and CPN and who must address typical problems that arise in the conduct of a high-technology systems project.

**Prerequisite**: Admission into the Systems Engineering program (not available for Technical Management students).

**Instructors**: Bernstein, Cormier, Hein, Jacobus, Olson, Saunders, Utara

**645.469 Systems Engineering of Deployed Systems**

Systems engineering theory typically focuses on the early design and development phases of a system's life cycle, yet over the life of a system, the bulk of engineering effort and the associated costs are not realized until the operations and support (O&S) phase. This course will examine the importance of designing O&S considerations early in a system's life cycle by identifying the appropriate logistic elements and measures, while introducing the necessary analytical processes and tools to support end-to-end life cycle engineering requirements. Manufacturing and production operations will be presented along with the elements that support a system once it is fielded (maintenance planning, reliability prediction, supply support, training, shipping, and system disposal). The course will also explore the requirements and processes associated with major upgrades to deployed systems and the logistics management techniques that must be implemented during initial fielding and deployment. A class project and real-world case studies will underscore the theory and techniques associated with deployed systems engineering.

**Prerequisite**: 645.462 Introduction to Systems Engineering or 645.467 Management of Systems Projects.

**Instructors**: Finlayson, Herdlick, Mayoral, Metz

**645.742 Management of Complex Systems**

Traditional systems engineering is usually applied to closed, precise, and recursive systems, with the assertion that the methodologies used can be scaled up to more elaborate systems of systems. This course addresses the more realistic and emerging field of the management of complex systems, where multiple current development efforts with disparate and nonlinear attributes characterize the system components. Engineering complex systems must account for the likelihood of multiple disciplines, differing scales, often unpredictable future states, irreducible uncertainty, and nonlinear behavior. Multiple customers, corporations, governments, technologies, and systems now must be considered on a global scale with a mix of new and legacy systems. The student will be encouraged to think differently and creatively about the management approaches to developing complex systems and to use adaptive strategies and tools including modeling and simulation, pattern recognition, nonlinear dynamics, chaos theory, and control systems. Special attention will be given to risk assessment and management for dynamic systems. Case studies and examples will be drawn from commercial industry and DoD systems acquisition programs. Students will be expected to discuss several readings and complete an academic paper to explore in depth one or more of the concepts discussed.

**Course Note**: Selected as one of the electives in the Master of Science in Engineering or Master of Science program or a required course in for the post-master's certificate

**Instructor**: Crownover

### 645.753 Enterprise Systems Engineering

Enterprise systems engineering is a multidisciplinary approach combining systems engineering and strategic management to address methods and approaches for aligning system architectures with enterprise business rules and the underlying IT architecture; development and implementation consistent with enterprise strategic objectives; and the total enterprise system and capabilities, with diverse complex subsystems. This course uses the systems engineering life cycle as a framework for linking outcome-based engineering analysis and decision making with enterprise strategic objectives, addressing methods and tools for managing complexity, determining measures of effectiveness, and assessing return on investment from an engineering perspective. The complex nature of enterprises will be discussed, including the multiplicity of technical and business components involved in delivering enterprise capability, as well as methods for modeling and analysis of their interdependence. Business and technical interdependencies between infrastructure, computing, applications, services, and end-user environments will be discussed. Particular attention will be paid to outcome-based management, understanding total cost of ownership for delivered capabilities, and end-to-end systems engineering.

**Course Note**: Selected as one of the electives in the Master of Science in Engineering or Master of Science program or a required course in for the post-master's certificate.

**Instructors**: Dahmann, Montoya, Ziarko

### 645.754 Social and Organizational Factors in Human Systems Engineering

The objective of this course is to provide students with the knowledge of organizational structure, social interaction, and group behavior needed to reflect the full context of use in the practice of systems engineering. It examines the characteristics of organizations and of social contexts that influence system requirements and design and describes systems engineering processes for discovering, representing, and analyzing such information in practice. It covers the application of these factors throughout the system life cycle. Additional topics include systems in high-reliability organizations, system support for group situational awareness and distributed decision making in command and control systems, and systems engineering for context-aware and social media systems.

**Prerequisite**: 645.462 Introduction to Systems Engineering.

**Instructors**: Bos, Gersh

### 645.755 Methods in Human-System Performance Measurement and Analysis

This course focuses on human-system performance measurement (HsPM) methods used to determine whether human-system requirements are met and whether the system's design provides effective and efficient human-system performance. Students will gain knowledge of HsPM study design protocols, data collection tools and methods, analysis techniques and processes, and procedures required to execute studies with human participants. The course will provide students with an understanding of HsPM in the context of system design; workplace design; environment, safety, and occupational health; training; and maintenance. Students will be exposed to heuristic evaluations; modeling and simulation of human tasking, including tools for measuring physical limitations, cognitive load, and fatigue; and system testing with the human element.

**Prerequisite**: 645.462 Introduction to Systems Engineering.

**Instructors**: Beecher, Comperatore

### 645.756 Metrics, Modeling, and Simulation for Systems Engineering

This course takes an integrated, in-depth view of foundational statistical concepts, modeling, and simulation techniques. Knowledge of typical system-level key performance parameters and their stochastic characterization is critical to the systems engineering process as the basis for decision making from early system conceptualization through retirement. Relevant probability and statistics concepts are covered in the context of systems engineering decision points. Techniques in experimental design, data collection, analysis, and modeling of system metrics as a function of system use and environment are explored as they pertain to characterizing system, subsystem, and component performance. Finally, implementing models in analytic simulations to support requirements, design, upgrade, and replacement/retirement phases of the systems engineering process provides the systems engineer with a solid foundation for making and justifying difficult decisions.

**Prerequisites**: 645.462 Introduction to Systems Engineering, 645.467 Management of Systems Projects, and 645.767 System Conceptual Design.

**Instructors**: Ruben, Ryals, West, Youngblood

### 645.757 Foundations of Modeling and Simulation in Systems Engineering

This course provides an introduction to the field of modeling and simulation (M&S) from the perspective of M&S as an essential tool for systems engineering. Topics emphasize the use of M&S to establish and verify key performance parameters, system and subsystem functionality, and interfaces. The course presents an overview of the types of models and simulations used across the phases of the systems engineering life cycle.

The strengths and limitations of M&S are explored with respect to the application of M&S use in systems engineering. Examples will be given for several types of systems, including systems developed under the US Department of Defense acquisition process. State-of-the-art M&S tools are introduced, and each student is given the opportunity to construct a model or simulation using a tool of his or her choice. The Arena modeling tool will be used for some examples. Upon completion of the course, the student will be able to recognize when M&S will provide meaningful support to a technical program, select the appropriate modeling techniques for a given task, lead the development of the model and the modeling of the input data, and analyze the results to support decisions at key milestones of a system's life cycle.

**Prerequisite**: 645.462 Introduction to Systems Engineering.

**Instructors**: Coolahan, Jones

### 645.758 Advanced Systems Modeling Simulation

This course is a continuation of Foundations of Modeling and Simulation in Systems Engineering and provides in-depth exposure to the field of modeling and simulation (M&S) from the perspective of M&S as an essential tool for systems engineering. Advanced statistical methods are used to conduct requirements-driven simulation analysis and experimentation. The course provides treatment of advanced M&S topics, including verification, validation, and accreditation techniques; methods for simulation interoperability and composability; modeling of the system environment, both natural and man-made; modeling of system costs; and the establishment of collaborative M&S environments. The course also explores continuous and real-time simulation. Students are exposed to the techniques used to form conceptual models of mechanical (both translational and rotational), electrical, fluid, thermal, biological, and hybrid systems. The conceptual models are transformed into mathematical models and implemented in a modern simulation package. State-of-the-art tools are explored, and each student is given the opportunity to conduct a simulation study of a complex system. Each student will present a case study and complete a project. Upon completion of the course, the student will be able to conduct or lead the development of the model of a complex physical system, model the input data, and analyze the results to support decisions at key milestones of a system's life cycle.

**Prerequisites**: 645.757 Foundations of Modeling and Simulation in Systems Engineering and 625.403 Statistical Methods and Data Analysis.

**Instructors**: Coolahan, Jones

### 645.761 Systems Architecting

As the systems that systems engineers face become more complex, it is no longer sufficient to use "good engineering practices." The complex systems of today need to be architected before design work can begin. This course examines the principles and art of systems architecting when developing both individual systems and systems that are components of a system or federation of systems. The objective is to provide students with the principles, techniques, and hands-on experience of architecting modern, complex systems. Students will learn the latest architecture development techniques using DoD and commercial architectural frameworks, then extend those frameworks to specific problems involving unique systems development environments. Topics include the management of underlying system and data models and the special architecting requirements of command, control, and communications systems. Special attention will be placed on visualizing architecture artifacts—qualitatively and quantitatively evaluating architectures and the systems model they represent—and using system architectures for investment decisions. Case studies from actual experiences will be presented.

**Course Note**: Selected as one of the electives in the Master of Science in Engineering or Master of Science program or a required course for the post-master's certificate.

**Instructors**: Henry, Smithson, Topper

### 645.764 Software Systems Engineering

This course for systems engineers covers software engineering principles, artifacts, and approaches for the development of software systems. Topics include software engineering processes and metrics; real-time, distributed, configurable, and object-oriented software; alignment of software systems with overall system design; software-unique aspects of planning, requirements, architecture analysis, design, implementation, testing, and maintenance; understanding important software engineering constraints (performance, security, networking, etc.); and technology trends in software engineering today. Student teams will conduct case studies for a project.

**Prerequisite**: 645.462 Introduction to Systems Engineering or permission from the student's academic advisor and the course instructor.

**Course Notes**: Students may not enroll in this course if they have already completed 595.763 Software Engineering Management. This course is not available to Technical Management students.

**Instructors**: Pafford, Saunders, Tamer, Thompson, Valencia

### 645.767 System Conceptual Design

This course addresses in detail the systems engineer's responsibilities and activities during the conceptual phases of a system development program. Systems engineering tools commonly employed at this stage of a program are presented along with selected problems that illustrate both the applicability and limitations of commonly employed tools and procedures. The course steps through conceptual design beginning with analysis of needs and objectives and proceeding to the exploration of alternative concepts and the selection of a concept that best meets goals of performance, timeliness, and affordability. Topics include definition of operational scenarios, functional analysis, risk assessment, system trade-offs, measures of effectiveness, and requirements formulation. Emphasis is on the application of these systems engineering techniques in a team environment to a class project. Students apply systems engineering methods learned from reading and lectures to the development of a realistic system in an ongoing project in a team format.

**Prerequisites**: 645.462 Introduction to Systems Engineering and 645.467 Management of Systems Projects, or permission of the student's advisor and the course instructor.

**Instructors**: Dixon, Flanigan, Levin, Russell, Ryder, Saxon, Secen, Smyth, Starr, Utara

### 645.768 System Design and Integration

This course addresses the systems engineering objectives, responsibilities, and activities during the demonstration and validation and the engineering and manufacturing development phases of a system development program. Systems engineering procedures and tools used during these phases are identified and their use illustrated. Topics include the relationship between a system specification and the system design, systems engineering management plans, risk management, system development models, customer integration into the design process, and design disciplines and practices. The course uses a system problem scenario extensively to illustrate systems engineering principles and specific product design issues.

**Prerequisite**: 645.767 System Conceptual Design or permission of the student's advisor and the instructor.

**Instructors**: Biemer, Campbell, Fidler, Harmatuk, Martinell, Saunders, Saxon, Secen, Utara, Warren, White

### 645.769 System Test and Evaluation

This course focuses on the application of systems engineering principles to the test and evaluation of system elements and, ultimately, of the total system. Test requirements, selection of critical test parameters, analysis of test results, and determination of remedial action in the event of discrepancies are all systems engineering functions. Topics include validation and verification, similarities and differences in the nature of hardware and software testing, test tools and test procedures, testing during hardware–software integration, quality assurance test, environmental test, and operational test and evaluation. Student problems include scenario case studies using examples developed in the several previous courses.

**Prerequisite**: 645.768 System Design and Integration or permission of the student's advisor and the instructor.

**Instructors**: Fidler, Finlayson, Harmatuk, Kim, Kryzstan, O'Connor, Selby, Sprigg, Tarchalski, Thompson, Ziarko

### 645.771 System of Systems Engineering

This course addresses the special engineering problems associated with conceiving, developing, and operating systems composed of groups of complex systems closely linked to function as integral entities. The course will start with the underlying fundamentals of systems' requirements, design, test and evaluation, and deployment, as well as how they are altered in the multi-system environment. These topics will then be extended to information flow and system interoperability, confederated modeling and simulation, use of commercial off-the-shelf elements, and systems engineering collaboration between different organizations. Advanced principles of information fusion, causality theory with Bayesian networks, and capability dependencies will be explored. Several case studies will be discussed for specific military systems of systems, including missile defense and combatant vehicle design, as well as selected commercial examples.

**Course Note**: Selected as one of the electives in the Master of Science in Engineering or Master of Science program or a required course for the post-master's certificate.

**Instructors**: Biemer, Ciotti, Fidler, Flanigan, Montoya

### 645.800 Systems Engineering Master's Project

This course provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific practical project that is suggested by the student and is presented in a formal proposal. The product of the system project is a final report; also required are interim reports and an oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the systems engineering faculty. The program chair, vice chair, and mentor review proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses (formerly 645.770). It is self-paced and often takes more than one semester to complete.

**Prerequisite**: 645.769 System Test and Evaluation or permission of the program chair or vice chair.

**Instructors**: Biemer, Utara

**645.801 Systems Engineering Master's Thesis**

This course is designed for students in the systems engineering master's program, who will work with an advisor to conduct independent research in the field of systems engineering, leading to a paper that is publishable in a refereed journal. It is also desirable that the paper be presented at a professional meeting. The intent of the research is to advance the body of knowledge and the understanding of systems engineering practices, the improvement of systems engineering practices in industry and in government, the evolution of systems engineering tools and techniques, and the solution of systems development issues in the acquisition of advanced systems. Students intending to pursue a doctoral degree should enroll in this course.

**Course Note**: Students who plan to register for this course will need to contact the Systems Engineering Program Office (443-778-6002) four to six weeks prior to the semester start date.

**Prerequisites**: Completion of all other courses applicable to the systems engineering master's degree.

**Instructor**: Strawser

**645.802 Systems Engineering Master's Thesis**

This course is designed for students in the systems engineering master's program, who will work with an advisor to conduct independent research in the field of systems engineering, leading to a paper that is publishable in a refereed journal. It is also desirable that the paper be presented at a professional meeting. The intent of the research is to advance the body of knowledge and the understanding of systems engineering practices, the improvement of systems engineering practices in industry and in government, the evolution of systems engineering tools and techniques, and the solution of systems development issues in the acquisition of advanced systems. Students intending to pursue a doctoral degree should enroll in this course.

**Course Note**: Students who plan to register for this course will need to contact the Systems Engineering Program Office (443-778-6002) four to six weeks prior to the semester start date.

**Prerequisites**: Completion of all other courses applicable to the systems engineering master's degree.

**Instructor**: Strawser

**645.803 Post Master's-Systems Engineering Research Project**

This course is designed for students in the systems engineering post-master's certificate program, who will work with an advisor to conduct independent research in the field of systems engineering, leading to a paper that is publishable in a refereed journal. It is also desirable that the paper be presented at a professional meeting. The intent of the research is to advance the body of knowledge and the understanding of systems engineering practices, the improvement of systems engineering practices in industry and in government, the evolution of systems engineering tools and techniques, and the solution of systems development issues in the acquisition of advanced systems.

**Prerequisites**: MSE or MS in Systems Engineering and three of the four required advanced post master's systems engineering courses.

**Course Note**: Students who plan to register for this course will need to contact the Systems Engineering Program Office (443-778-6002) four to six weeks prior to the semester start date.

**Instructor**: Faculty

**645.804 Post Master's-Systems Engineering Research Project**

This course is designed for students in the systems engineering post-master's certificate program, who will work with an advisor to conduct independent research in the field of systems engineering, leading to a paper that is publishable in a refereed journal. It is also desirable that the paper be presented at a professional meeting. The intent of the research is to advance the body of knowledge and the understanding of systems engineering practices, the improvement of systems engineering practices in industry and in government, the evolution of systems engineering tools and techniques, and the solution of systems development issues in the acquisition of advanced systems.

**Prerequisites**: MSE or MS in Systems Engineering and three of the four required advanced post master's systems engineering courses.

**Course Note**: Students who plan to register for this course will need to contact the Systems Engineering Program Office (443-778-6002) four to six weeks prior to the semester start date.

**Instructor**: Faculty

**645.805 Biomedical Systems Engineering Master's Project**

This course is intended for students in the biomedical systems engineering concentration and provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific biomedical systems project that is suggested by the student and is presented in a formal proposal. The product of the biomedical system project is a final report; also required are interim reports and an oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the biomedical or systems engineering faculty. The biomedical program chair, the systems engineering vice chair, a systems engineering mentor, and a biomedical mentor review student proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses.

**Prerequisites**: Completion of all courses applicable to the Biomedical Systems Engineering focus area.

**Instructor**: Faculty

### 645.806 Cybersecurity Systems Engineering Master's Project 🏛

This course is intended for students in the Cybersecurity Systems Engineering concentration and provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific cybersecurity system project that is suggested by the student and is presented in a formal proposal. The product of the cybersecurity system project is a final report; also required are interim reports and an oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the computer science or systems engineering faculty. The computer science program chair, the systems engineering vice chair, a systems engineering mentor, and a computer science mentor review student proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses.

**Prerequisites**: Completion of all other courses applicable to the Cybersecurity Systems Engineering focus area

**Instructor**: Faculty

### 645.807 Software Systems Engineering Master's Project 🏛

This course is intended for students in the software systems engineering focus area and provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific software systems project that is suggested by the student and is presented in a formal proposal. The product of the software systems project is a final report; also required are interim reports and an oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the computer science or systems engineering faculty. The computer science program representative, the systems engineering vice chair, a systems engineering mentor, and a computer science mentor review student proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses.

**Prerequisite**: Completion of all other courses applicable to the Software Systems Engineering focus area.

**Instructor**: Faculty

### 645.808 Human Systems Engineering Master's Project 🏛

This course is intended for students in the human systems engineering concentration and provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific human systems project that is suggested by the student and is presented in a formal proposal. The product of the human systems project is a final report; also required are interim reports and an oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the systems engineering or human systems concentration faculty. The systems engineering chair, a systems engineering mentor, and a human systems concentration mentor review student proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses.

**Prerequisite**: Completion of all courses applicable to the Human Systems Engineering focus area.

**Instructor**: Faculty

## SPACE SYSTEMS ENGINEERING

### 675.401 Fundamentals of Engineering Space Systems I VL

The effective development of space systems is predicated on a firm understanding of the foundational technical, programmatic, and systems engineering components necessary to both comprehend the design task and develop an appropriate solution. For engineers and technical managers seeking to develop this working knowledge and the associated skills, this course will provide an overview of the key elements comprising space systems. With a strong systems engineering context, topics will include fundamentals on space environments, astro-dynamics, propulsion, attitude determination and control, power systems, communications, thermal management, and command and data handling. Classes will feature a combination of instruction from subject matter experts, review of prevailing and emerging technologies for space applications, and a team design project.

**Prerequisite**: An undergraduate degree in physics or engineering, or the equivalent.

**Instructors**: Rogers, Faculty

### 675.402 Fundamentals of Engineering Space Systems II VL

This course will build on the material covered in 675.401 Fundamentals of Engineering Space Systems I, expanding on the breadth and depth of topics, as well as their integrated application. Once equipped with a working understanding of the subsystem components, technical considerations, and their associated analysis methods, the course will focus on the systems engineering of space vehicles, instruments, experiments, and entire missions. Classes will again feature a combination of instruction from subject matter experts and a team design project.

**Prerequisite**: 675.401 Fundamentals of Engineering Space Systems I.

**Instructors**: Rogers, Faculty

**675.701 Space Systems Engineering Technical Seminar**

The seminar course, composed of weekend classes and workshops on the Applied Physics Laboratory campus or via virtual live, will give students the opportunity to hear from experts in the design of space systems as well as government sponsors. Concurrently the students will work on a team project that initiates the design of a "tabletop" satellite. This design will continue as part of the Capstone Project.

**Instructors**: Rogers, Faculty

**675.710 Space Systems Engineering Capstone Project**

The Capstone Project will be completed in a team setting on the Applied Physics Laboratory campus on weekends or via virtual live. Students will work in groups of four on space-related projects such as a Cubesat design. The project will require students to design and build a "tabletop" functional spacecraft model to incorporate all phases of the design, including reviews, quality assurance plans and other documentation, as well as review boards. The department will purchase kits from EyasSat. Additional information can be found on the company's website (eyassat.com). These tabletop satellite model kits are especially designed for educational purposes.

**Instructors**: Rogers, Faculty

**675.721 Space Environment and Space Weather**

This course addresses general topics related to the space environment and how changes therein impact life on Earth. The course starts with an introduction to plasma physics principles (science that describes the space environment) and then it outlines the environments between the Sun and Earth and their impacts on energy flow, satellite survivability, and ground-based technologies. Topics include the Sun, solar wind and interplanetary space, the Magnetosphere, the Ionosphere, the Atmosphere, and geomagnetism. Students will gain a global understanding of the Space Environment and the daily impacts of space weather, especially pertaining to the design of spacecraft and commercial industries.

**Instructor**: Mitchell

**Offered**: Fall

**675.800 Directed Studies in Space Systems Engineering**

In this course, qualified students are permitted to investigate possible research fields or to pursue problems of interest through reading or non-laboratory study under the direction of faculty members.

**Prerequisites**: The Independent Study/Project Form (ep.jhu.edu/student-forms) must be completed and approved prior to registration.

**Course Note**: This course is open only to candidates in the Master of Science in Space Systems Engineering program.

**Instructors**: Rogers, Faculty

# CYBERSECURITY

**695.401 Foundations of Information Assurance**

This course surveys the broad fields of enterprise security and privacy, concentrating on the nature of enterprise security requirements by identifying threats to enterprise information technology (IT) systems, access control and open systems, and system and product evaluation criteria. Risk management and policy considerations are examined with respect to the technical nature of enterprise security as represented by government guidance and regulations to support information confidentiality, integrity, and availability. The course develops the student's ability to assess enterprise security risk and to formulate technical recommendations in the areas of hardware and software. Aspects of security-related topics to be discussed include network security, cryptography, IT technology issues, and database security. The course addresses evolving Internet, Intranet, and Extranet security issues that affect enterprise security. Additional topics include access control (hardware and software), communications security, and the proper use of system software (operating system and utilities). The course addresses the social and legal problems of individual privacy in an information processing environment, as well as the computer "crime" potential of such systems. The class examines several data encryption algorithms.

**Instructors**: Ambuel, Heinbuch, Pak, Podell, Tarr, Valenta

**695.411 Embedded Computer Systems–Vulnerabilities, Intrusions, and Protection Mechanisms**

While most of the world is preoccupied with high-profile network-based computer intrusions, this online course examines the potential for computer crime and the protection mechanisms employed in conjunction with the embedded computers that can be found within non-networked products (e.g., vending machines, automotive on-board computers, etc.). This course provides a basic understanding of embedded computer systems: differences with respect to network-based computers, programmability, exploitation methods, and current intrusion protection techniques, along with material relating to computer hacking and vulnerability assessment. The course materials consist of a set of eight study modules and five case-study experiments (to be completed at a rate of one per week) and are augmented by online discussion forums moderated by the instructor. This course also includes online discussion forums that support greater depth of understanding of the materials presented within the study modules.

**Prerequisites**: 695.401 Foundations of Information Assurance and a basic understanding and working knowledge of computer systems and access to Intel-based PC hosting a Microsoft Windows environment.

**Instructor**: Kalb

### 695.421 Public Key Infrastructure and Managing E-Security

This course describes public key technology and related security management issues in the context of the Secure Cyberspace Grand Challenge of the National Academy of Engineering. Course materials explain Public Key Infrastructure (PKI) components and how the various components support e-business and strong security services. The course includes the basics of public key technology; the role of digital certificates; a case study which emphasizes the content and importance of certificate policy and certification practices; identification challenges and the current status of the National Strategy for Trusted Identities in Cyberspace; and essential aspects of the key management life cycle processes which incorporate the most recent research papers of the National Institute of Standards and Technology. Students will examine PKI capabilities and digital signatures in the context of the business environment, including applicable laws and regulations. The course also presents the essential elements for PKI implementation, including planning, the state of standards, and interoperability challenges. The course also provides an opportunity for students to tailor the course to meet specific cyber-security interests with regard to PKI and participate in discussions with their peers on contemporary cyber-security topics.

**Instructor**: Mitchel

### 695.422 Web Security

This course examines issues associated with making web applications secure. The principal focus is on server-side security such as CGIsecurity, proper server configuration, and firewalls. The course alsoinvestigates the protection of connections between a client and server usingcurrent encryption protocols (e.g., SSL/TLS) as well discussing the relatedattacks on these protocols (e.g. Heartbleed, CRIME, etc). The course alsoinvestigates keeping certain data private from the server system (e.g., viathird party transaction protocols like SET, or PCI DSS standard). ElementaryNumber Theory will be reviewed. Finally, the course explores client-sidevulnerabilities associated with browsing the web, such as systempenetration, information breach, identity theft, and denial-of-serviceattacks. Related topics such as malicious emails, web bugs, spyware,and software security are also discussed. Labs and various server sidedemonstrations enable students to probe more deeply into securityissues and to develop and test potential solutions. Basic knowledge ofoperating systems is recommended. Students will download and installa Virtual Machine to be used in the course.

**Prerequisite**: 605.412 Operating Systems or basic knowledge of operating systems is recommended.

**Instructors**: Ching, McGuire

### 695.442 Intrusion Detection

This course explores the use of intrusion detection systems (IDS) as part of an organization's overall security posture. A variety of approaches, models, and algorithms, along with the practical concerns of deploying IDS in an enterprise environment, will be discussed. Topics include the history of IDS, anomaly and misuse detection for both host and network environments, and policy and legal issues surrounding the use of IDS. The use of ROC (receiver operating characteristic) curves to discuss false positives and missed detection trade-offs, as well as discussion of current research topics, will provide a comprehensive understanding of when and how IDS can complement host and network security. TCPDump and Snort will be used in student assignments to collect and analyze potential attacks.

**Course Note**: Formerly 695.423 Intrusion Detection.

**Instructors**: Ching, Longstaff

### 695.443 Introduction to Ethical Hacking

This course exposes students to the world of computer hacking. The primary goal is to give students an understanding of how vulnerable systems can be attacked as a means to motivate how they might be better defended. The class takes a systems engineering view of hacking and emphasizes practical exposure via hands-on assignments. Students are expected to use a computer that will remain off all networks while they complete assignments.

**Prerequisites**: 695.401 Foundations of Information Assurance and 635.411 Principles of Network Engineering or 605.471 Principles of Data Communication Networks, or equivalent experience

**Course Note**: Homework assignments will include programming.

**Instructors**: Buckman, Llanso, Smeltzer

**695.701 Cryptology**

This course provides an introduction to the principles and practice of contemporary cryptology. It begins with a brief survey of classical cryptographic techniques that influenced the modern development of cryptology. The course then focuses on contemporary work: symmetric block ciphers and the Advanced Encryption Standard, public key cryptosystems, digital signatures, authentication protocols, and cryptographic hash functions. Pertinent ideas from complexity theory and computational number theory, which provide the foundation for much of the contemporary work in cryptology, are introduced as needed throughout the course.

**Instructors**: May, Zaret

**695.711 Java Security**

This course examines security topics in the context of the Java language, with emphasis on security services such as confidentiality, integrity, authentication, access control, and non-repudiation. Specific topics include mobile code, mechanisms for building "sandboxes" (e.g., class loaders, namespaces, bytecode verification, access controllers, protection domains, policy files), symmetric and asymmetric data encryption, hashing, digital certificates, signature and MAC generation/verification, code signing, key management, SSL, and object-level protection. Various supporting APIs are also considered, including the Java Cryptography Architecture (JCA) and Java Cryptography Extension (JCE). Security APIs for XML and web services, such as XML Signature and XML Encryption, Security Assertions Markup Language (SAML), and Extensible Access Control Markup Language (XACML), are also surveyed. The course includes multiple programming assignments and a project.

**Prerequisites**: 605.481 Principles of Enterprise Web Development

or equivalent. Basic knowledge of XML. 695.401 Foundations of Information Assurance or 695.422 Web Security would be helpful but is not required.

**Instructor**: Ceesay

**695.712 Authentication Technologies in Cybersecurity**

Authentication technologies in cybersecurity play an important role in identification, authentication, authorization, and non-repudiation of an entity. The authentication process in cybersecurity, which is considered to be one of the weakest links in computer security today, takes many forms as new technologies such as cloud computing, mobile devices, biometrics, PKI, and wireless are implemented. Authentication is the security process that validates the claimed identity of an entity, relying on one or more characteristics bound to that entity. Entities can be, but are not limited to, software, firmware, physical devices, and humans. The course explores the underlying technology, the role of multi-factor authentication in cybersecurity, evaluation of authentication processes, and the practical issues of authentication. Several different categories and processes of authentication will be explored, along with password cracking techniques, key logging, phishing, and man-in-the-middle attacks. Examples of authentication breaches and ethical hacking techniques will be explored to examine the current technologies and how they can be compromised. Case studies of authentication system implementation and their security breaches will be presented. Federated authentication process over different network protocols, topologies, and solutions will be addressed. Related background is developed as needed, allowing students to gain a rich understanding of authentication techniques and the requirements for using them in a secure environment including systems, networks, and the Internet. Students will apply the key components and concepts of key issues in authentication to real world scenarios.

**Prerequisites**: 695.401 Foundations of Information Assurance. 695.421 Public Key Infrastructure and Managing E-Security is recommended.

**Instructor**: Pak

**695.721 Network Security**

This course covers concepts and issues pertaining to network security and network security architecture and evolving virtualization and related cloud computing security architecture. Topics include mini-cases to develop a network security context. For example, we will assess the NIST (National Institute of Standards and Technology) unified information security framework. This framework is supported by information security standards and guidance, such as a risk management framework (RMF) and continuous monitoring (CM) process. Applied cryptography and information security– encryption algorithms; hash algorithms; message integrity checks; digital signatures; security assessment and authentication, authorization, and accounting (AAA); security association; and security key management (generation, distribution, and renewal)–are discussed, with consideration given to emerging cryptographic trends, such as the evolution and adoption of NSA's (National Security Agency's) Suite B cryptography. This course presents network and network security architecture viewpoints for selected security issues, including various security mechanisms, different layers of wired/ wireless security protocols, different types of security attacks and threats and their countermeasures or mitigation, next-generation network (NGN) security architecture that supports the merging of wired and wireless communications, and Internet Protocol version 6 implementation and transition. The course concludes with more comprehensive cases that consider network security aspects of virtualization and cloud computing architecture.

**Prerequisites**: 695.401 Foundations of Information Assurance and 605.471 Principles of Data Communications Networks or 635.411 Principles of Network Engineering.

**Instructors**: Heinbuch, Podell

### 695.741 Information Assurance Analysis

This course provides students with an overview of analysis as it applies to information assurance. Analysis is a fundamental part of the information assurance process, and effective analysis informs policy, software development, network operations, and criminal investigations. To enable students to perform effective analysis, the focus of the course is on the analysis process and approach rather than on specific tools. Topics include the collection, use, and presentation of data from a variety of sources (e.g., raw network traffic data, traffic summary records, and log data collected from servers and firewalls). These data are used by a variety of analytical techniques, such as collection approach evaluation, population estimation, hypothesis testing, experiment construction and evaluation, and constructing evidence chains for forensic analysis. Students will construct and critique an analytical architecture, construct security experiments, and retroactively analyze events. The course will also cover selected nontechnical ramifications of data collection and analysis, including anonymity, privacy, and legal constraints.

**Prerequisites**: 695.401 Foundations of Information Assurance. Familiarity with basic statistical analysis. 695.442 Intrusion Detection or 695.411 Embedded Computer Systems–Vulnerabilities, Intrusions, and Protection Mechanisms is recommended.

**Instructors**: Anthony, Collins

### 695.742 Digital Forensics Technologies and Techniques

Digital forensics focuses on the acquisition, identification, attribution, and analysis of digital evidence of an event occurring in a computer or network. This course provides a broader scientific understanding of the technologies and techniques used to perform digital forensics. In particular, various signature extraction techniques, detection, classification, and retrieval of forensically interesting patterns will be introduced. This will be complemented by studying fundamental concepts of data processing technologies such as compression, watermarking, steganography, cryptography, and multi-resolution analysis. Emerging standards along with issues driving the changing nature of this topic will be explored. Anti-forensic techniques that are used to counter forensic analysis will also be covered. Students will be exposed to relevant theory, programming practice, case studies, and contemporary literature on the subject.

**Prerequisite**: 605.412 Operating Systems.

**Instructor**: Ahmed

### 695.744 Reverse Engineering and Vulnerability Analysis

This course covers both the art and science of discovering software vulnerabilities. Beginning with the foundational techniques used to analyze both source and binary code, the course will examine current threats and discuss the actions needed to prevent attackers from taking advantage of both known and unknown vulnerabilities. The course will cover passive and active reverse engineering techniques in order to discover and categorize software vulnerabilities, create patches and workarounds to better secure the system, and describe security solutions that provide protection from an adversary attempting to exploit the vulnerabilities. Techniques covered include the use of static analysis, dynamic reverse engineering tools, and fault injection via fuzzing to better understand and improve the security of software.

**Course Note**: Formerly 695.714 Reverse Engineering and Vulnerability Analysis.

**Instructor**: McGuire

### 695.791 Information Assurance Architectures and Technologies

This course explores concepts and issues pertaining to information assurance architectures (IAA) and technologies, such as cryptographic commercial issues, layered security or defense-in-depth, methods and technologies for critical information infrastructure protection (CIIP), cloud computing security architecture, and IAA and technologies applications. Topics include selected US and international CIIP and Comprehensive National Cybersecurity Initiative (CNCI) Trusted Internet Connections (TIC) multi–agency security information and event management (SIEM) issues. Commercial IAA examples of network security architecture and SIEM are also discussed for evolving enterprise wired and wireless services. The relationships of IAA and technologies with selected multitier architectures are discussed for applications such as risk management and enterprise architecture (EA) disciplines, security for virtualized environments, secure software engineering for services, and secure telecommunication for transport. IAA multitier architecture issues are illustrated with cases, such as the National Institute of Standards and

Technology's (NIST)-recommended three-tier approach for organization-wide risk management and a three-tier security controls architecture developed for cybersecurity standards for CIIP that is compatible with guidance from NIST and the International Telecommunication Union-Telecommunication Standardization Sector Study Group 17. Selected applied IAA and technologies are examined in large-scale programs, such as CNCI TIC; the Federal Aviation Administration (FAA) System Wide Information Management (SWIM) Program; and NIST Smart Grid Cyber Security Strategy, Architecture, and High-Level Requirements.

**Prerequisites**: 695.401 Foundations of Information Assurance or equivalent, and 605.471 Principles of Data Communications Networks or 635.411 Principles of Network Engineering.

**Instructor**: Podell

### 695.801 Independent Study in Cybersecurity I

This course permits graduate students in information assurance to work with a faculty mentor to explore a topic in depth or conduct research in selected areas. Requirements for completion include submission of a significant paper or project.

**Prerequisites**: Seven Cybersecurity graduate courses including the foundation courses, three track-focused area courses, and two courses numbered at the 700 level or admission to the postmaster's certificate program. Students must also have permission from the instructor.

### 695.802 Independent Study in Cybersecurity II

Students wishing to take a second independent study in Cybersecurity should sign up for this course.

**Prerequisites**: 695.801 Independent Study in Information Assurance I and permission of a faculty mentor, the student's academic advisor, and the program chair.

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Principal Professional Staff
JHU Applied Physics Laboratory

VINCENT PISACANE *retired*

GONZALO PITA
Senior Consultant
The World Bank

TERENCE PLAZA
Senior Program Manager
Raytheon

SIMON PLUNKETT
Astrophysicist
Naval Research Lab

HAROLD PODELL
Assistant Director-IT Security
U. S. Government Accountability Office

BRIAN POKRZYWA
Systems Engineering Director
Northrop Grumman Corporation

THOMAS POLE
Engineer
Harris Corporation

DAVID L. PORTER
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JHU Applied Physics Laboratory

RICHARD POTEMBER
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CHRIS POWERS
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Charles A. Miller Jr. Distinguished Professor of Mechanical Engineering
JHU Whiting School of Engineering

ALAN PUE

LIXIN QIE

JEFF RAFFENSPERGER
Research Hydrologist
U.S. Geological Survey

SANKAR RAGHAVAN *retired*
Program Coordinator, Chemical and Biomolecular Engineering
Johns Hopkins Engineering for Professionals
Instructor
JHU Whiting School of Engineering

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Senior Professional Staff
JHU Applied Physics Laboratory

GREGORY READ

MOHAMED TAMER REFAEI
Senior Scientist
The MITRE Corporation

DANIEL REGAN
Capture Director/ Staff Vice President
Anthem, Inc. / National Government Services, Inc.

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ARTHUR REYNOLDS

RANDY RICHARDS
Engineering Fellow
Raytheon

KURT RIEGEL
Director, Environmental Technology
Antares Group

DANIEL RIO

JEFFREY RITTER
CEO
Self Employed

MICHAEL ROBERT
Branch Head
U.S. Naval Surface Warfare Center

ROBBIN RODDEWIG
CEO
ERAS Inc.

BENJAMIN RODRIGUEZ
Principal Professional Staff
JHU Applied Physics Laboratory

AARON Q. ROGERS
Senior Professional Staff
JHU Applied Physics Laboratory

JOHN ROMANO
Director of Technology & Security
University of Maryland, College Park

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Micronic Technology Corp.

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BRUCE RUSSELL
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CARL RYBA
JHU Applied Physics Laboratory

CHRISTOPHER RYDER
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Senior Principal Engineer
Signalscape, Incorporated

PATRICK SAIN
Senior Principal Systems Engineer
Raytheon

WALID SALEH
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JENNIFER L. SAMPLE
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JOHN SAMSUNDAR
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RACHEL SANGREE
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SAMUEL SCHAPPELLE
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SEEMA SCHAPPELLE

HARRY SCHEPERS
Vice President
Praxis Engineering

TIM SCHEVE
Senior Manager, Systems Engineering
Raytheon

PHIL SCHIED

TOD SCHUCK
Principal Engineering Fellow
Lockheed Martin

DAVID SCHUG
Computer Scientist
Naval Air Warfare Center Aircraft Division (NAWCAD)

ALBERT SECEN
Systems Engineer
Lockheed Martin

HELMUT SEIFERT
Principal Professional Staff
JHU Applied Physics Laboratory

JONATHAN SELBY
Systems Engineer
Johns Hopkins University

BRIAN SEQUEIRA
Principal Professional Staff
JHU Applied Physics Laboratory

NAWAZ SHARIF
Principal Consultant
Myriad Solutions, Inc

JOHN SHEPPARD
Professor
Montana State University

DAVID SHERMAN
Research Professor
JHU School of Medicine

JIN SHIN
Principal Environmental Engineer
Washington Suburban Sanitary Commission

STEPHEN A. SHINN
Deputy Director, Flight Projects
NASA Goddard Space Flight Center

JOEL SHOLTES
Graduate Research Assistant
Colorado State University

KARTHIK SHYAMSUNDER
Principal Technologist
VeriSign, Inc.

DONG-JYE SHYY
Principal Communications Engineer
The MITRE Corporation

STANLEY SIEGEL *retired*
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JHU Whiting School of Engineering

DAVID SILBERBERG
Principal Professional Staff
JHU Applied Physics Laboratory

EMIL SIMIU
NIST Fellow
Florida International University

TIMOTHY SIMPSON

MICHAEL SMELTZER
JHU Applied Physics Laboratory

CHRISTOPHER SMITH
Deputy Director
Raytheon

DEXTER SMITH
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JHU Whiting School of Engineering

THOMAS SMITH
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JERRY SMITH

CLYDE SMITHSON
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EDWARD A. SMYTH
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Lecturer
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IRA SORENSEN
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TATYANA SOROKINA
Towson University

RAYMOND M. SOVA
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JHU Applied Physics Laboratory

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Johns Hopkins Engineering for Professionals
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Research Professor, Department of Applied Mathematics and Statistics
JHU Whiting School of Engineering

ALEXANDER SPECTOR
Research Professor
JHU Whiting School of Engineering

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Senior Associate
Wiss, Janney, Elstner Associates, Inc.

GORDON SPRIGG
Consultant
Self Employed

JAMES STAFFORD
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SRA International, Inc.

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Loyola University Maryland

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U.S. Army Research Office

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JHU Applied Physics Laboratory

JAY STERN
Mission Assurance Director
Raytheon

LEONID STERN
Professor
Towson University

LYNNE STEVENS
Director, Systems Engineering
Raytheon Missile Systems

ANDREW STODDARD
Principal Environmental Engineer
Dynamic Solutions, LLC.

KATHY STRAUB
Principal
Usability.org

LARRY STRAWSER
Adjunct Faculty
JHU Whiting School of Engineering

ROBERT SUMMERS *retired*

SUSAN SUPPLEE
Senior Contracting Officer
U.S. Naval Air Systems Command (NAVAIR)

JOSEPH J. SUTER
Program Chair, Engineering Management and Technical Management
Acting Chair, Space Systems Engineering
Johns Hopkins Engineering for Professionals
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Director, Systems Architectures
Raytheon

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JOHN TAMER
Principal Professional Staff
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STANISLAW TARCHALSKI *retired*
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JULIE TARR
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U.S. Naval Air Systems Command (NAVAIR)

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JOHN THOMAS
JHU Applied Physics Laboratory

MICHAEL E. THOMAS
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Associate Research Professor
Morgan State University

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U.S. Army Research Laboratory

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CRAIG TOUSSAINT
President
JHU Whiting School of Engineering

DAVID TUCKER
Civil Engineer
U.S. Army Corps of Engineers

ALPER UCAK
Engineering Designer
Parsons Brinckerhoff

ALEKSANDR UKHORSKIY
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THOMAS URBAN
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Command–AIR 4.6

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SHON VICK
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JEFFREY WADSWORTH
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Raytheon Missile Systems

TREVEN WALL

SHUANGZHEN WANG

SUE-JANE WANG
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U.S. Food and Drug Administration

YANG WANG
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JOSH WEISS
Associate
Hazen and Sawyer P.C.

FRANK WELLS
Lead Operations Research Analyst
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JIM WYANT *retired*

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Senior Professional Staff
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ED ZHOU
National Practice Leader
URS Corporation

JANICE ZIARKO
Principal Organizational Analytics Consultant
The MITRE Corporation

GERALD ZUELSDORF

# POLICY STATEMENTS

## EQUAL OPPORTUNITY/NONDISCRIMINATORY POLICY AS TO STUDENTS

The Johns Hopkins University is committed to recruiting, supporting, and fostering a diverse community of outstanding faculty, staff, and students. As such, Johns Hopkins does not discriminate on the basis of gender, marital status, pregnancy, race, color, ethnicity, national origin, age, disability, religion, sexual orientation, gender identity or expression, veteran status, or other legally protected characteristic in any student program or activity administered by the university or with regard to admission or employment. Defense Department discrimination in Reserve Officer Training Corps (ROTC) programs on the basis of sexual orientation conflicts with this university policy. The university continues its ROTC program, but encourages a change in the Defense Department Policy.

Questions regarding Title VI, Title IX, and Section 504 should be referred to the Office of Institutional Equity, 410-516-8075 or (TTY) 410-516-6225.

## POLICY ON THE RESERVE OFFICER TRAINING CORPS

The Johns Hopkins University admits students of any race, color, gender, religion, age, national or ethnic origin, disability, marital status, or veteran status to all of the rights, privileges, programs, benefits, and activities generally accorded or made available to students at the university. It does not discriminate on the basis of race, color, gender, marital status, pregnancy, ethnicity, national origin, age, disability, religion, sexual orientation, gender identity or expression, veteran status, or other legally protected characteristic in any student program or activity administered by the university, including the administration of its educational policies, admission policies, scholarship and loan programs, and athletic and other university-administered programs or in employment.

Questions regarding Title VI, Title IX, and Section 504 should be referred to the Office of Institutional Equity, Garland Hall 130, 410-516-8075, (TTY) 410-516-6225.

## STATEMENT REGARDING THE PRIVACY RIGHTS OF STUDENTS

Notice is hereby given that the Johns Hopkins Engineering for Professionals program complies with the provisions of the Family Educational Rights and Privacy Act (FERPA) of 1974 (P.L. 93-380), as amended, and regulations promulgated thereunder. FERPA affords eligible students with certain rights with respect to their education records. These rights are as follows: (1) The right to inspect and review the student's education records within forty-five days of the day the university receives a request for access. Students should submit to the Registrar written requests that identify the record(s) they wish to inspect. The Registrar will make arrangements for access and notify the student of the time and place where the records may be inspected. If the records are not maintained by the Registrar, the student will be advised of the correct official to whom the request should be addressed. (2) The right to request amendment of education records that the student believes are inaccurate or misleading. Students should write to the university official responsible for the record they want changed and specify why it is inaccurate or misleading. If the university decides not to amend the records as requested by the student, the student will be notified of the decision and advised of his or her right to a hearing regarding the request for amendment. Additional information regarding the hearing procedures will be provided to the student when notified of the right to a hearing. (3) The right to consent to disclosures of personally identifiable information contained in the student's education records, except to the extent that FERPA authorizes disclosures without consent. Disclosure without consent is granted to school officials with legitimate educational interests. A school official is a person employed by the university in an administrative, supervisory, academic or research, or support staff position (including law enforcement unit personnel and health staff); a person serving on the board of trustees; or a student serving on an official committee, such as a disciplinary or grievance committee, or assisting another school official in performing his or her tasks. A school official has a legitimate educational interest if the official needs to review an education record in order to fulfill his or her professional responsibility. (4) The right to file a complaint with the US Department of Education concerning alleged failures by the university to comply with the requirements of FERPA.

The name and address of the office that administers FERPA is:

Family Policy Compliance Office
US Department of Education
400 Maryland Avenue S.W.
Washington, DC 20202-4605

## AMERICANS WITH DISABILITIES ACT POLICY (ADA)

The Johns Hopkins University does not discriminate on the basis of gender, marital status, pregnancy, race, color, ethnicity, national origin, age, disability, religion, sexual orientation, veteran status or other legally protected characteristic in any student program or activity administered by the university or with regard to admission or employment.

A person with a disability is defined by the Rehabilitation Act of 1973 and by the Americans with Disabilities Act of 1990 as an individual who has a physical or mental impairment that substantially limits one or more major life activities, has a record of such an impairment, or is regarded as having such an impairment. For persons with disabilities it is important to provide to the university a comprehensive evaluation of a specific disability from an appropriate qualified diagnostician that identifies the type of disability, describes the current level of functioning in an academic or employment setting and lists recommended accommodations. The university provides appropriate, necessary, and reasonable accommodations in programs and facilities for those individuals who are qualified.

The policy is available on the Johns Hopkins University Office of Institutional Equity (OIE) website at web.jhu.edu/administration/jhuoie/disability/index.html. Questions regarding compliance with the provisions of the Americans with Disabilities Act of 1990 and Section 504 of the Rehabilitation Act of 1973 should be referred to Disability Services, Office of Institutional Equity, 410-516-8949 or (TTY) 410-516-5300.

## SEXUAL HARASSMENT PREVENTION AND RESOLUTION POLICY

### PREAMBLE

The Johns Hopkins University is committed to providing its staff, faculty, and students the opportunity to pursue excellence in their academic and professional endeavors. This can exist only when each member of our community is assured an atmosphere of mutual respect, one in which they are judged solely on criteria related to academic or job performance. The university is committed to providing such an environment, free from all forms of harassment and discrimination. Each member of the community is responsible for fostering mutual respect, for being familiar with this policy, and for refraining from conduct that violates this policy.

Sexual harassment, whether between people of different sexes or the same sex, is defined to include, but is not limited to, unwelcome sexual advances, requests for sexual favors, and other behavior of a sexual nature when:

1. Submission to such conduct is made implicitly or explicitly a term or condition of an individual's employment or participation in an educational program
2. Submission to or rejection of such conduct by an individual is used as the basis for personnel decisions or for academic evaluation or advancement
3. Such conduct has the purpose or effect of unreasonably interfering with an individual's work or academic performance or creates an intimidating, hostile, or offensive working or educational environment

Fundamental to the university's purpose is the free and open exchange of ideas. It is not, therefore, the university's purpose, in promulgating this policy, to inhibit free speech or the free communication of ideas by members of the academic community.

### POLICY

The university will not tolerate sexual harassment, a form of discrimination, a violation of federal and state law, and a serious violation of university policy. In accordance with its educational mission, the university works to educate its community regarding sexual harassment. The university encourages individuals to report incidents of sexual harassment and provides a network of confidential consultants by which individuals can report complaints of sexual harassment. The means by which complaints are resolved can range from informal to formal.

The university encourages reporting of all perceived incidents of sexual harassment, regardless of who the alleged offender may be. Individuals who either believe they have become the victim of sexual harassment or have witnessed sexual harassment should discuss their concerns with any member of the Sexual Harassment Prevention and Resolution system. Complainants are assured that problems of this nature will be treated in a confidential manner, subject to the university's legal obligation to respond appropriately to any and all allegations of sexual harassment.

The university prohibits acts of reprisal against anyone involved in lodging a complaint of sexual harassment. Conversely, the university considers filing intentionally false reports of sexual harassment a violation of this policy.

The university will promptly respond to all complaints of sexual harassment. When necessary, the university will institute disciplinary proceedings against the offending individual, which may result in a range of sanctions, up to and including termination of university affiliation.

Complaints of sexual harassment may be brought to Susan Boswell, Dean of Student Life, 410-516-8208; Ray Gillian, Vice Provost for Institutional Equity; or Caroline Laguerre-Brown, Director of Equity Compliance and Education, 410-516-8075 or (TTY) 410-516-6225.

## UNIVERSITY ALCOHOL AND DRUG POLICY FOR STUDENTS

In keeping with its basic mission, the university recognizes that its primary response to issues of alcohol and drug abuse must be through educational programs, as well as through intervention and treatment efforts. To that end, the university provides appropriate programs and efforts throughout the year. The brochure "Maintaining a Drug-Free Environment: The Hopkins Commitment" is distributed annually to all faculty, students, and staff of the Johns Hopkins University, and copies are available on request from the offices of the Faculty and Staff Assistance Program, 4 East 33rd Street, Baltimore, Maryland 21218, 410-516-3800; or at the Counseling and Student Development Center located on the Homewood Campus, 410-516-8270.

## POLICY ON POSSESSION OF FIREARMS ON UNIVERSITY PREMISES

Possessing, wearing, carrying, transporting, or using a firearm or pellet weapon is strictly forbidden on university premises. This prohibition also extends to any person who may have acquired a government-issued permit or license. Violation of this regulation will result in disciplinary action and sanctions up to and including expulsion in the case of students, or termination of employment in the case of employees. Disciplinary action for violations of this regulation will be the responsibility of the divisional student affairs officer, dean or director, or the vice president for human resources, as may be appropriate, in accordance with applicable procedures. Any questions regarding this policy, including the granting of exceptions for law enforcement officers and for persons acting under the supervision of authorized university personnel, should be addressed to the appropriate chief campus security officer.

## CAMPUS SECURITY ACT NOTICE

In accordance with the Crime Awareness and Campus Security Act of 1990 (P.L. 102-26), as amended, and the regulations promulgated thereunder, the university issues its Annual Security Report that describes the security services at each of the university's divisions and reports crime statistics for each of the campuses. The report is published online at jhu.edu/~security/annual_report.pdf. Copies of the report are available from the university's Security Department, 14 Shriver Hall, 3400 North Charles Street, Baltimore, Maryland 21218-2689, 410-516-4600.

## PHOTOGRAPH AND FILM RIGHTS POLICY

The Johns Hopkins University reserves the right from time to time to film or take photographs of faculty, staff, and students engaged in teaching, research, clinical practices, and other activities, as well as casual and portrait photography or film. These photographs and films will be used in such publications as catalogs, posters, advertisements, recruitment and development materials, as well as on the university's website, for various videos, or for distribution to local, state, or national media for promotional purposes. Classes will be photographed only with the permission of the faculty member.

Such photographs and film—including digital media—will be kept in the files and archives of The Johns Hopkins University and remain available for use by the university without time limitations or restrictions. Faculty, students, and staff are made aware by virtue of this policy that the university reserves the right to alter photography and film for creative purposes.

Faculty, students, and staff who do not want their photographs used in the manner(s) described in this policy statement should contact the Office of Communications and Public Affairs. Faculty and students are advised that persons in public places are deemed by law to have no expectation of privacy and are subject to being photographed by third parties. The Johns Hopkins University has no control over the use of photographs or film taken by third parties, including without limitation the news media covering university activities.

## RETURN OF TITLE IV FUNDS POLICY

The Financial Aid Office is required by federal statute to recalculate federal financial aid eligibility for students who withdraw, drop out, are dismissed, or take a leave of absence prior to completing sixty percent of a payment period or term. The federal Title IV financial aid programs must be recalculated in these situations. If a student leaves the institution prior to completing sixty percent of a payment period or term, the Financial Aid Office recalculates eligibility for Title IV funds. Recalculation is based on the percentage of earned aid using the following federal return of Title IV funds formula: Percentage of payment period or term completed = the number of days completed up to the withdrawal date divided by the total days in the payment period or term. (Any break of five days or more is not counted as part of the days in the term.) This percentage is also the percentage of earned aid. Funds are returned to the appropriate federal program based on the percentage of unearned aid using the following formula: Aid to be returned = (one hundred percent of the aid that could be disbursed minus the percentage of earned aid) multiplied by the total amount of aid that could have been disbursed during the payment period or term. If a student earned less aid than was disbursed, the institution would be required to return a portion of the funds and the student would be required to return a portion of the funds. Keep in mind that when Title IV funds are returned, the student borrower may owe a debit balance to the institution. If a student earned more aid than was disbursed to him/her, the institution would owe the student a post-withdrawal disbursement, which must be paid within 120 days of the student's withdrawal. The institution must return the amount of Title IV funds for which it is responsible no later than thirty days after the date of the determination of the date of the student's withdrawal.

Refunds are allocated in the following order:

- Unsubsidized Federal Stafford loans
- Subsidized Federal Stafford loans
- Unsubsidized Direct Stafford loans (other than PLUS loans)
- Subsidized Direct Stafford loans
- Federal Perkins loans
- Federal Parent (PLUS) loans
- Direct PLUS loans
- Federal Pell Grants for which a return of funds is required
- Federal Supplemental Opportunity grants for which a return of funds is required
- Other assistance under this Title for which a return of funds is required (e.g., LEAP)

# TRUSTEES AND ADMINISTRATION

## PRINCIPAL ADMINISTRATIVE OFFICES AND DEANS

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President of the University

DAVID W. ANDREWS
Dean of the School of Education

KERRY A. ATES
Vice President and Chief of Staff

GLENN M. BIELER
Vice President for Communications

LOIS CHIANG
Senior Adviser to the President

KATHRYN J. CRECELIUS
Vice President, Investments and Chief Investment Officer

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Dean of the School of Nursing

DANIEL G. ENNIS
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Dean of the Carey Business School

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Vice President for Facilities and Real Estate

ANDREW B. FRANK
Special Adviser to the President on Economic Development

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Vice President for Planning and Budget

CHARLENE MOORE HAYES
Vice President for Human Resources

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Frances Watt Baker and Lenox D. Baker, Jr.
Dean of the School of Medicine

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Vice President and General Counsel

T. E. SCHLESINGER
Dean, Whiting School of Engineering

RALPH D. SEMMEL
Director of Applied Physics Laboratory

PHILLIP SPECTOR
Vice President, Strategic Initiatives

WINSTON TABB
Sheridan Dean of University Libraries and Museums

CHRISTY WYSKIEL
Senior Adviser to the President for Enterprise Development

# DIRECTIONS AND MAPS

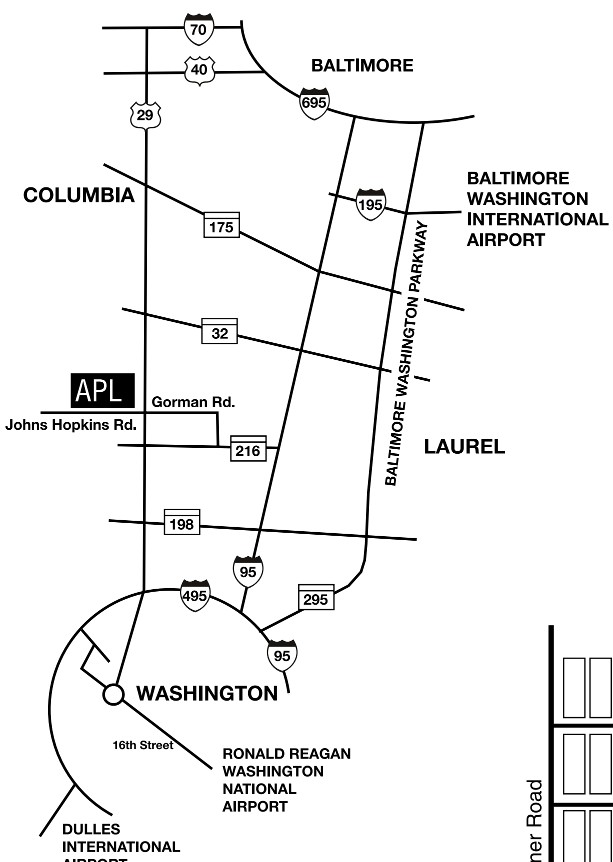
## APPLIED PHYSICS LABORATORY

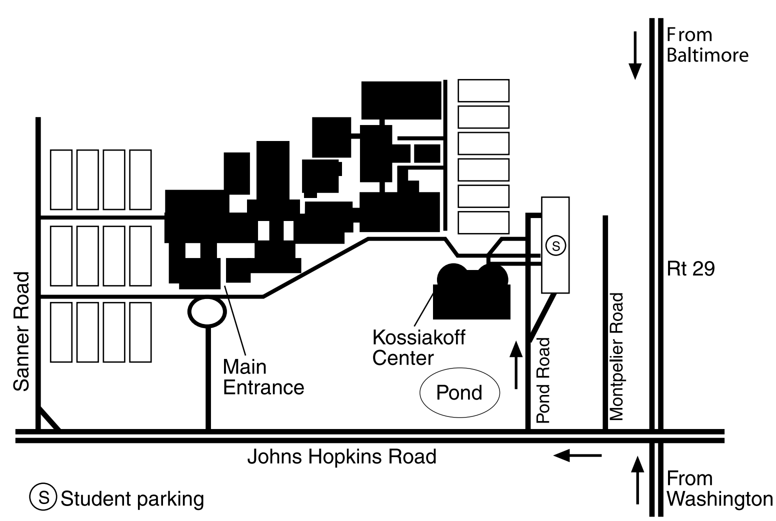
11100 Johns Hopkins Road, Kossiakoff Center, Room K215, Laurel, MD 20723-6099
443-778-6510 (Baltimore) 240-228-6510 (Washington, DC)

*From Baltimore and I-95 (southbound)*: Take I-95 South from the Baltimore Beltway (I-695) intersection. Go 13 miles and take the Columbia exit (MD Route 32 West). Go 2.5 miles and take the Washington DC exit (US Route 29 South). Go 1.5 miles and take the Johns Hopkins Road exit. APL is on the right, about 0.5 mile. Turn right onto Pond Road, and follow the signs to the Kossiakoff Center parking on the lower lot.

*From Washington and I-95 (northbound)*: Take I-95 North from the Capital Beltway (I-495) toward Baltimore. Go 8 miles and take MD Route 216 West (toward Scaggsville). Go 1.2 miles and turn right onto Leishear Road. Go 0.8 mile and turn left onto Gorman Road. Go 0.7 mile and cross the traffic circle and bridge over US Route 29. The road name changes to Johns Hopkins Road. APL is on the right, about 0.5 mile. Turn right onto Pond Road, and follow the signs to the Kossiakoff Center parking on the lower lot.

*From US Route 29*: Proceed on US 29 to the Johns Hopkins Road exits. APL is about 0.5 mile west. Turn right on Pond Road, and follow the signs to the Kossiakoff Center parking on the lower lot.



# CRYSTAL CITY CENTER

## CENTURY CENTER II BUILDING, SUITE 1200

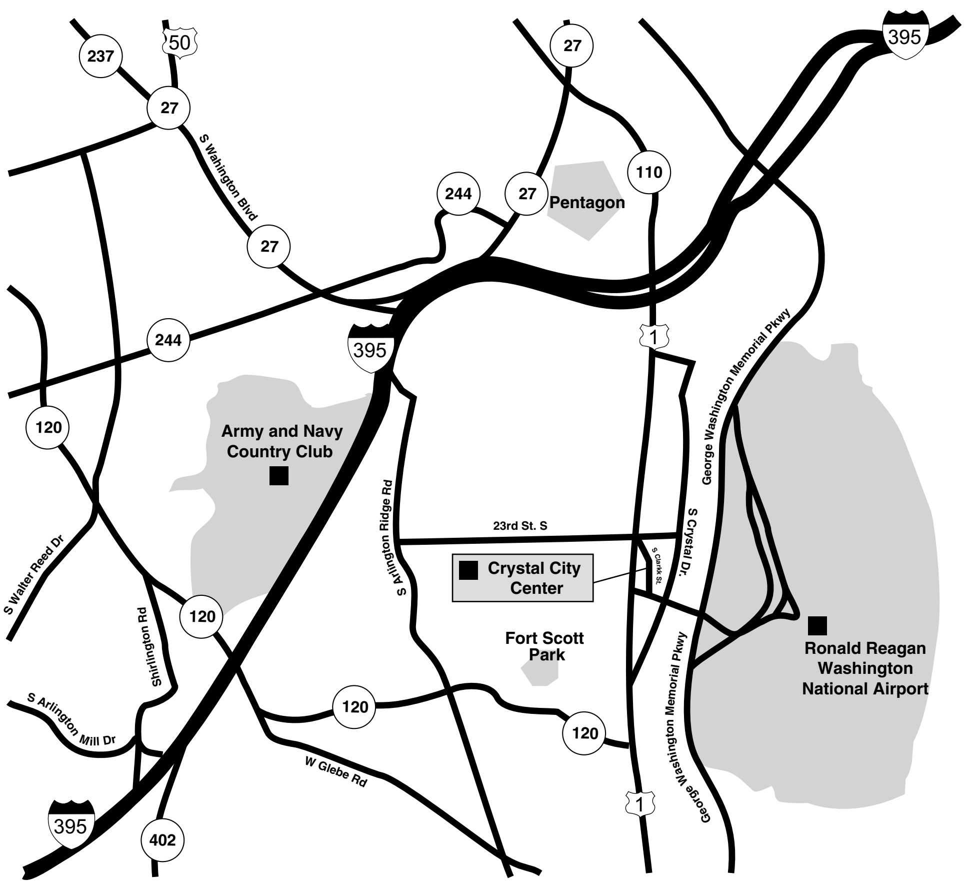
2461 South Clark Street, Arlington, Virginia 22202
240-228-2912

*From the South*: Take I-95/I-395 Northbound toward Washington, D.C. Follow I-95 North to I-395 North. Continue on I-395 to South Glebe Road, Exit 7A. Turn left onto US-1 North / Jefferson Davis HWY. Turn right onto 23rd Street South and an immediate right onto S. Clark Street. 2461 S. Clark Street is on the left.

*From Baltimore or North*: Take MD-295 South / Baltimore Washington Parkway. Merge onto US-50 / New York Ave N.E (crossing into Washington, D.C.). Take I-395 South toward TUNNEL (crossing into Virginia). Merge onto US-1 South / Jefferson Davis HWY via Exit 8C on the left toward Pentagon City /Crystal City. Turn left onto 23rd Street South and an immediate right onto S. Clark Street. 2461 S. Clark Street is on the left.

*From the I-270 Corridor / Germantown /Frederick, MD*: Take I-270 South toward Washington, D.C. Keep right to take the I-270 SPUR South I-270 / Washington / I-495 / Northern Virginia. I-270 SPUR south becomes I-495 south / Capital Beltway (crossing into Virginia). Take the George Washington PKWY, Exit 43 toward Washington. Take the National Airport Exit (crossing overpass toward Crystal City). Take US-1 North / Jefferson Davis HWY. Turn right onto 23rd Street South and an immediate right onto S. Clark Street. 2461 S. Clark Street is on the left.

*From the Annapolis, MD Area*: Merge onto US-50 West toward Washington, D.C / New York Ave N.E (crossing into Washington, D.C.). Take I-395 South toward TUNNEL (crossing into Virginia). Merge onto US-1 South / Jefferson Davis HWY via Exit 8C on the left toward Pentagon City /Crystal City. Turn left onto 23rd Street South and an immediate right onto S. Clark Street. 2461 S. Clark Street is on the left.

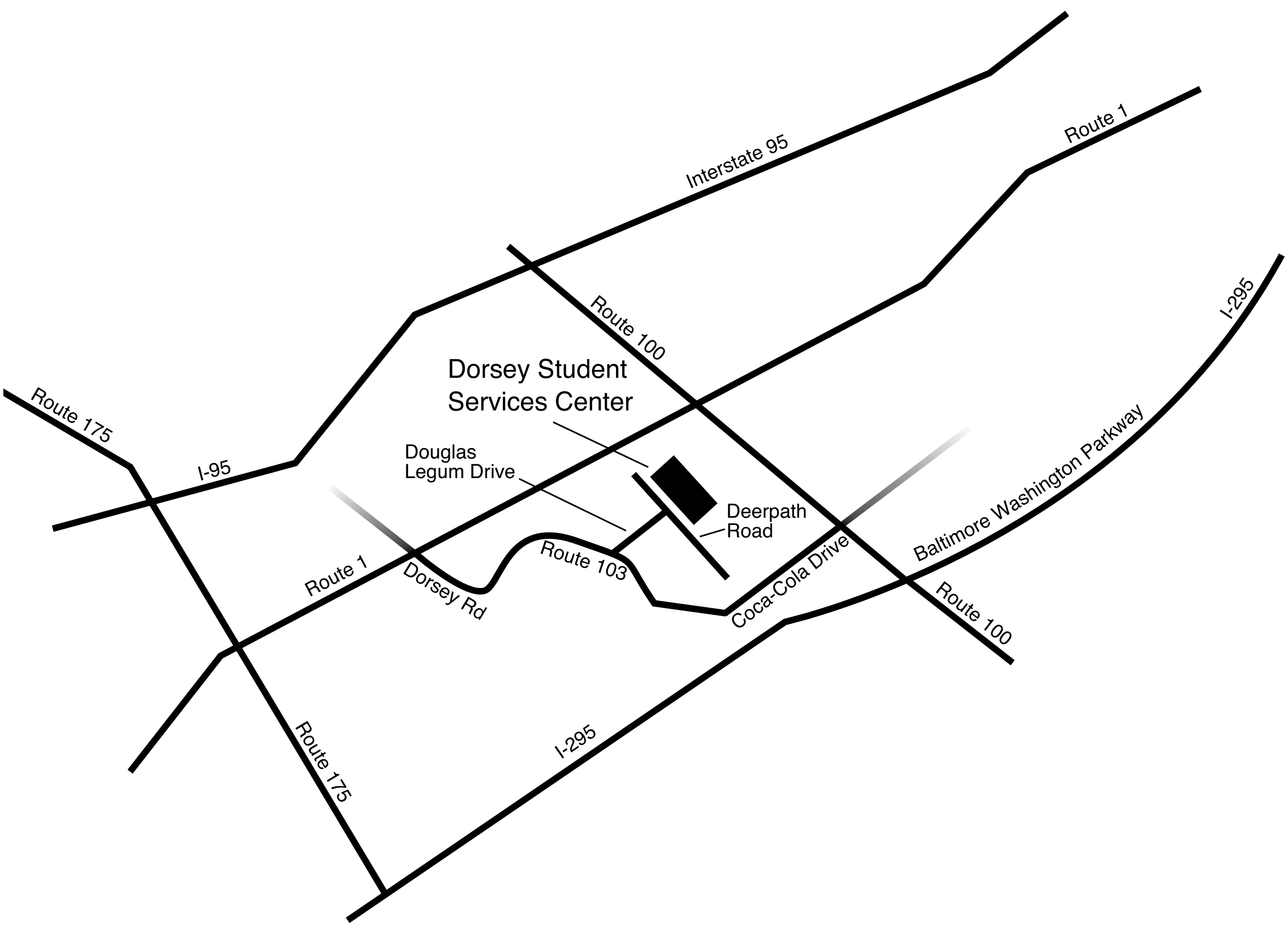


# DORSEY STUDENT SERVICES CENTER
## DORSEY BUSINESS PARK

6810 Deerpath Road, Suite 100, Elkridge, MD 21075
410-516-2300    800-548-3647

*From I-95 North or South*: Exit I-95 toward Route 100 East. Exit Route 100 toward Route 1 South. On Route 1, move to the inside lane. At the first light, turn left onto Dorsey Road (Route 103). After about one-third mile on Dorsey Road, turn left onto Douglas Legum Drive. Once on Douglas Legum Drive, the Dorsey Center is on the second floor of the five-story white building with blue windows.

*From I-295 (Baltimore Washington Parkway) North or South*: Exit I-295 toward Route 100 West. Exit Route 100 using the Coca Cola Drive exit. Turn left onto Coca Cola Drive toward Dorsey Road. At the end of Coca Cola Drive, turn right onto Dorsey Road. After about 1 mile on Dorsey Road, turn right onto Douglas Legum Drive. Once on Douglas Legum Drive, the Dorsey Center is on the second floor of the five-story white building with blue windows.



## HOMEWOOD CAMPUS
### JOHNS HOPKINS UNIVERSITY

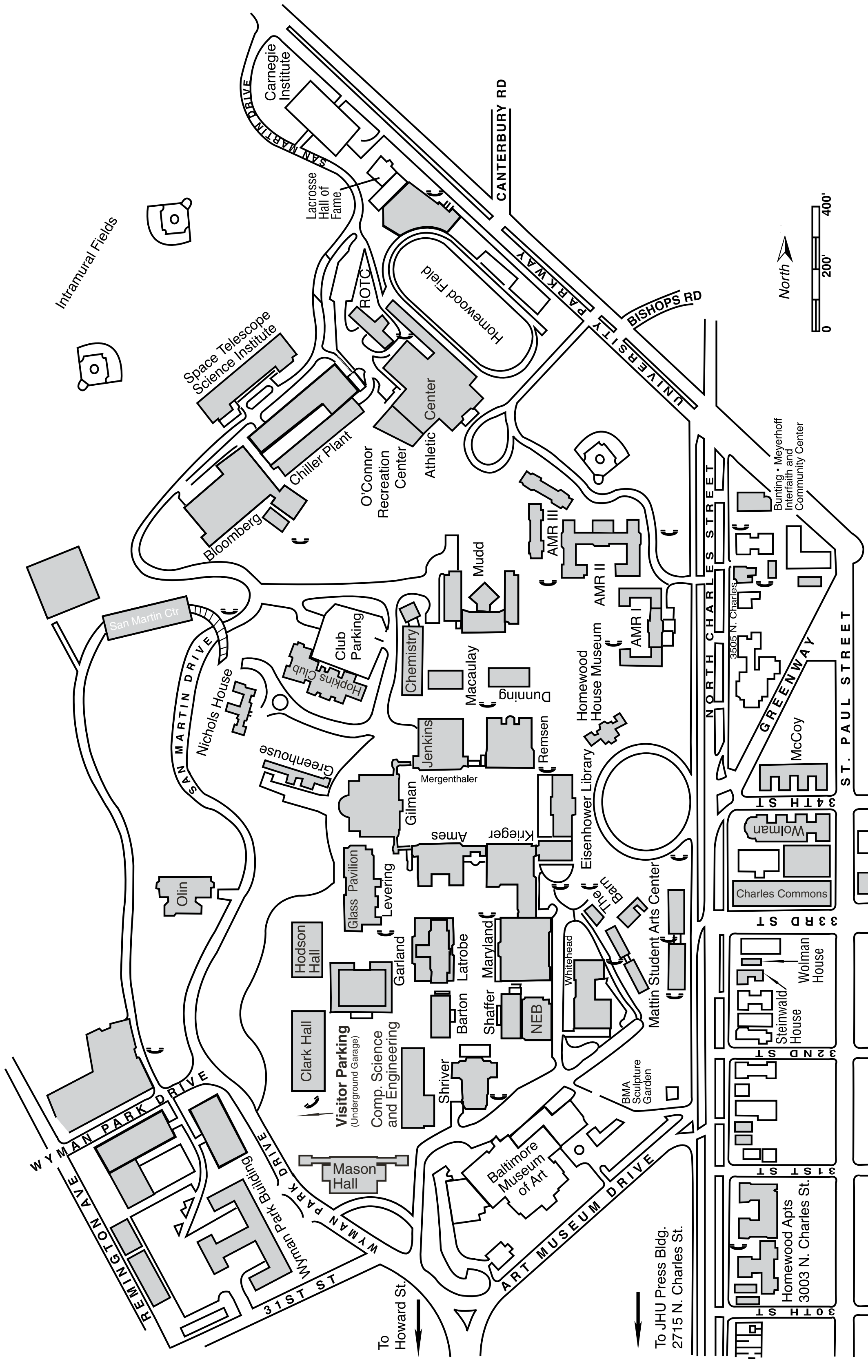
3400 N. Charles Street, Baltimore, MD 21218
410-516-8000

*From I-95 (southbound) or from I-695 (the Baltimore Beltway)*: Take the beltway toward Towson to Exit 25. Take Charles Street south for about 7 miles (when Charles Street splits a block after Loyola College and Cold Spring Lane, take the right fork). As you approach the university and cross University Parkway, continue southbound, but be sure to jog right onto the service road. After you pass the university on the right, turn right onto Art Museum Drive. Just after the Baltimore Museum of Art, bear right at the traffic island onto Wyman Park Drive. Take an almost immediate right through the university gates.

*From I-95 (northbound): Exit at I-395, then take the exit to Martin Luther King Jr. Boulevard and follow the directions below. From Maryland 295 (the Baltimore-Washington Parkway)*: Entering Baltimore, the parkway becomes Russell Street. Stay on Russell Street until (with Oriole Park at Camden Yards looming before you) you reach the right-hand exit marked Martin Luther King Jr. Boulevard (look carefully for this; the signs are small). Take Martin Luther King Jr. Boulevard until it ends at Howard Street (remain in one of the middle lanes of Martin Luther King Jr. Boulevard to avoid a premature forced right or left turn). Turn left at Howard Street and proceed about 2 miles. One block past 29th Street (where Howard Street becomes Art Museum Drive), turn left at the traffic island (just before the Baltimore Museum of Art) onto Wyman Park Drive. Take an almost immediate right through the university gates.

*From the Jones Falls Expressway (I-83) southbound*: Take the 28th Street exit to 28th Street east. Turn left on Howard Street. One block past 29th Street (where Howard Street becomes Art Museum Drive), turn left at the traffic island (just before the Baltimore Museum of Art) onto Wyman Park Drive. Take an almost immediate right through the university gates.

## HOMEWOOD CAMPUS *(CONTINUED)*



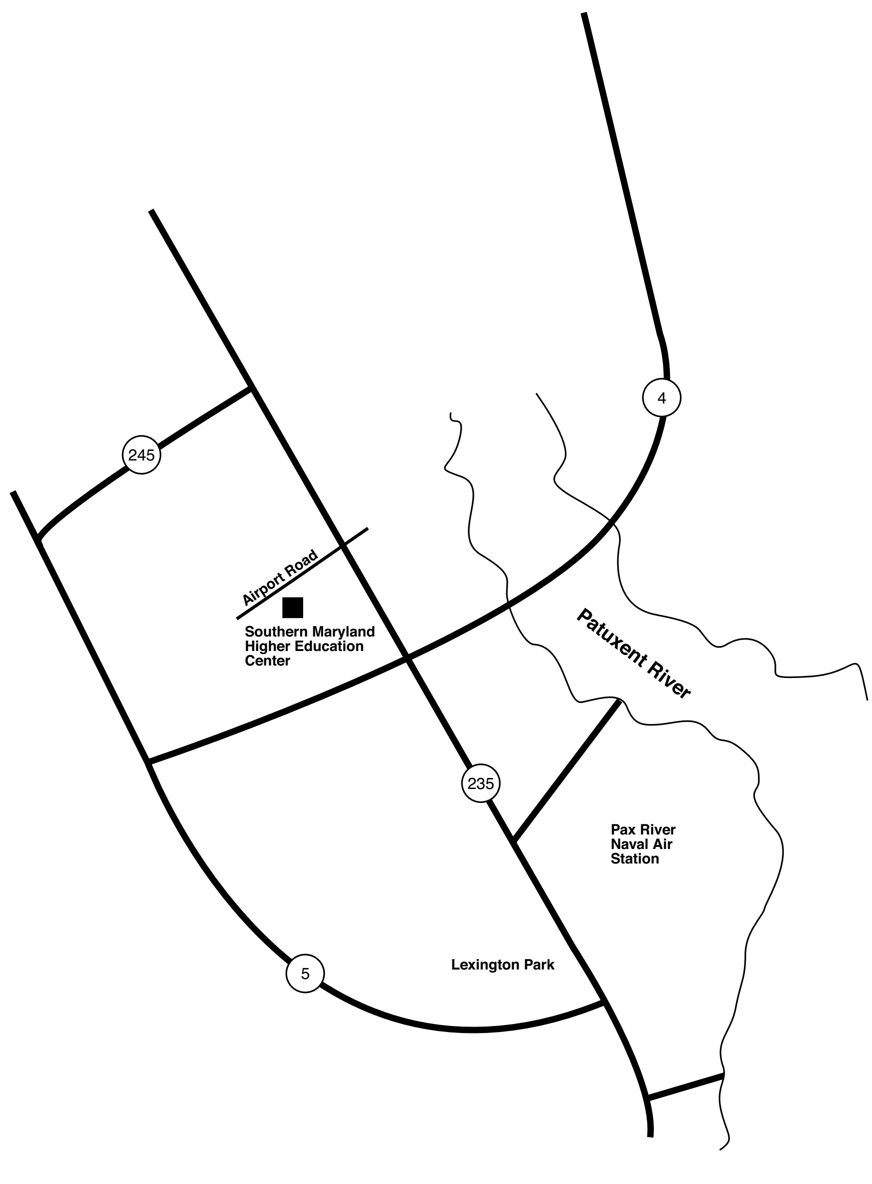
## SOUTHERN MARYLAND HIGHER EDUCATION CENTER

44219 Airport Road, Wildewood Technology Park, California, MD 20619
301-737-2500

*From Lexington Park*: Take MD Route 235 North approximately six miles to Airport Road. Turn left on Airport Road, and go about one-fourth mile to the Southern Maryland Higher Education Center on the left.

*From Calvert County*: Take MD Route 4 South. At Solomons, cross the Thomas Johnson Bridge, and continue 4 miles to the stoplight at MD Route 235. Turn right on Route 235, and go north past the Wildwood Shopping Center to Airport Road. Turn left on Airport Road, and go about one-fourth mile to the Southern Maryland Higher Education Center on the left.

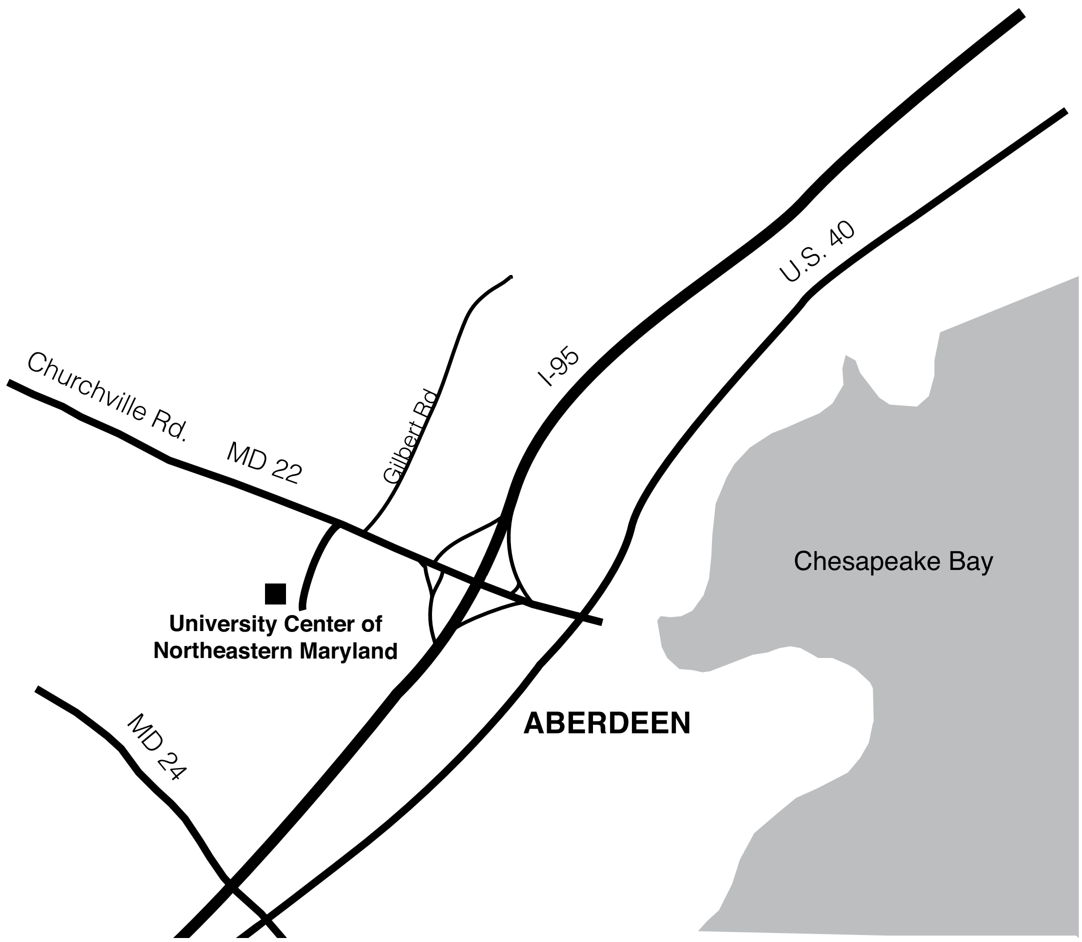
*From Charles County*: Take MD Route 5 South to St. Mary's County. About 20 miles south of Waldorf, Route 5 branches to the right toward Leonardtown, and the main four-lane road continues straight and becomes MD Route 235. Continue on Route 235 approximately 12 miles to Airport Road. Turn right on Airport Road, and go about one-fourth mile to the Southern Maryland Higher Education Center on the left.



## UNIVERSITY CENTER OF NORTHEASTERN MARYLAND

1201 Technology Drive, Aberdeen, MD 21001
443-360-9102

*From Baltimore and Washington, DC, area*: Take I-95 North to Exit 85, Route 22, toward Aberdeen/Churchville. Keep left at the fork in the ramp. Turn left onto Churchville Road (Route 22). Turn left onto Technology Drive. The center is on the left-hand side.



# INDEX

## A



## B

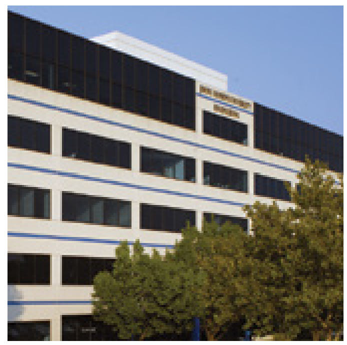


## C

The Johns Hopkins University
3400 North Charles Street
Baltimore, MD 21218

Applied Physics Laboratory
Laurel, MD

Crystal City Center
Arlington, VA



Dorsey Center
Elkridge, MD

Homewood
Baltimore, MD

Southern Maryland
Higher Education Center
California, MD

University Center of
Northeastern Maryland
Aberdeen, MD

Online